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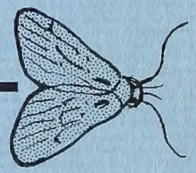
Response of Insects to Induced Light



PRESENTATION PAPERS

Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

PREFACE

This publication contains the presentation papers given at a symposium on the response of insects to induced light, sponsored by the Agricultural Research Service of the U. S. Department of Agriculture, which was held at the Agricultural Research Center, Beltsville, Maryland, February 3 and 4, 1960. For the purposes of this symposium the radiant energy considered was defined as visible, ultraviolet, and infrared electromagnetic radiations having a wavelength range of 2,000 to 1,000,000 Angstrom units. Between 80 and 90 scientists attended this symposium as representatives of Federal and State research and regulatory agencies and industrial companies.

The speakers discussed the nature of light sources; methods of applying induced light to influence insect response; the effects of light characteristics on insect response; the physiology of insect response to light; effects of species; effects of environment and physiological development on insect responses; and the possibilities and limitation of light traps for use in insect detection, prediction, and control.

It is hoped that both the symposium and this publication of the presentation papers will contribute to a better understanding of the relationship of light to insect responses and will stimulate further basic and applied research, leading to greater use of radiant energy in meeting insect problems.

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INTRODUCTION

T. C. Byerly[1]

In the development of its research program, the Agricultural Research Service has placed emphasis on basic research. A few problems have been segregated in some 15 or 16 areas wherein a pioneering research effort has been recognized.

It is the ARS policy to encourage and on occasion to insist upon the formation of teams of workers competent in different disciplines to undertake the solution of a particular problem. The problem of light traps was chosen for consideration for several reasons. First of all, the light response of insects has been recognized since the first moth flew into the first flame. Many people have tried to apply usefully the photo response of insects. In spite of these efforts, the response has not been sufficiently effective to make light traps the method of choice for insect control generally or until recently for survey methods. It is puzzling that this should be true. It appears that there has been no systematic study of the total range of intensities and of wavelengths with respect to any one insect under any one set of circumstances or with respect to any one insect under systematic variations of environment, such as temperature, humidity, and food supply. It should be possible to define rigorously some of the physical variables and to organize a team project that would obtain the basic quantitative data necessary for the evaluation of the possibilities and limitations of the use of light traps.

The problem of light traps is particularly timely because of the general concern with respect to problems resulting from the use of chemicals to control insects. This use is one of the most urgent and serious problems which agriculture, in fact society as a whole, has to face. The light-trap situation is also timely because it is illustrative of the general condition of research in agriculture. A great deal of piecemeal information is available on many subjects. In general this is the way research proceeds. People who have had ideas have followed them to some conclusion and published the information they have gathered with the evaluation of that information that seemed best to them. With light traps, as in the field of chemicals, research has proceeded piecemeal--a bit here and a bit there--some pieces of information have been produced, but the gaps between them cannot be readily bridged by interpolation, and attempts at extrapolation thus far have been ineffective.

The object of the papers reported in this publication is to serve as an assembly of and additions to the findings of this piecemeal research and to indicate where the defects and most serious gaps are in our present knowledge of the subject. In this way, it may make an important contribution to either individual or team research on problems involving the response of insects to light, sound, or other physical stimuli.

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SECTION I--CHARACTER AND SOURCE OF LIGHT

THE NATURE OF LIGHT SOURCES AND TYPES OF TRAPS

T. E. Hienton[1]

Light is defined in a very recent issue of a collegiate dictionary, in these words: "1 a) that which makes it possible to see: opposed to darkness; form of radiant energy that acts upon the retina of the eye, optic nerve, etc., making sight possible: this energy is transmitted at a velocity of about 186,000 miles per second by wavelike or vibrational motion b) a form of radiant energy similar to this, but not acting on the normal retina, as ultraviolet and infrared radiation."

Radiant energy is defined as "any form of energy radiating from a source, as electromagnetic waves, sound, heat, light, X-rays, gamma rays, etc." The chart on p. 3 shows that all of these forms of radiant energy, excepting sound, are included in one continuous electromagnetic spectrum. All of these show a wave nature and have the same speed in a vacuum as that of light, 186,000 miles per second.

Electromagnetic radiations, being of a wave nature, have the fundamental properties of waves, namely frequency and wavelength. The numerical product of the two is equal to the velocity, 186,000 miles per second, as previously indicated.

Thus the wavelength of our common electric service, operating at a frequency of 60 cycles per second would be 3,100 miles and velocity would be 60 x 3100 = 186,000 miles per second. At the cosmic ray or opposite end of the spectrum the wavelength is four 10-trillionths of an inch or 0.0001 Angstrom. It will be noted from the accompanying chart that wavelength is listed in Angstroms (A.), a unit commonly used. It is equal to one 10-millionth of a millimeter, or roughly 4 billionths of an inch. The millimicron ($m\mu$), equal to 10 A., and micron, equal to 10,000 A., are also commonly used units in the visible spectrum band.

The portion of the spectrum--ultraviolet, visible, and infrared--with which we are concerned is relatively small, comprising less than one-third of the entire spectrum. Further, the visible portion--3800-7600 A.--is a very small part of the whole radiation spectrum.

The second section of the chart includes the region we are considering the ultraviolet, visible, and part of the infrared. The remaining infrared (50,000-10,000,000 A.) is shown in the first section. Your attention is called particularly to the curve showing the relative energy of the sun's radiation reaching the earth. I would also invite attention to the mercury and sodium lines shown at the bottom of the third graph as they will be evident in spectral distribution curves of certain lamps which will be shown later. Note the four mercury lines in the visible and seven in the ultraviolet. The single sodium line is at 5893 A.

The eye sensitivity curve showing the relative response of the human eye to visible radiation may be seen in the center of the bottom graph. This is more readily apparent from a color slide which emphasizes the preponderance of normal eye sensitivity to the green, yellow, and orange with relatively little in the blue and red. Further reference will be made to this curve by Mr. Hollingsworth in his discussion.

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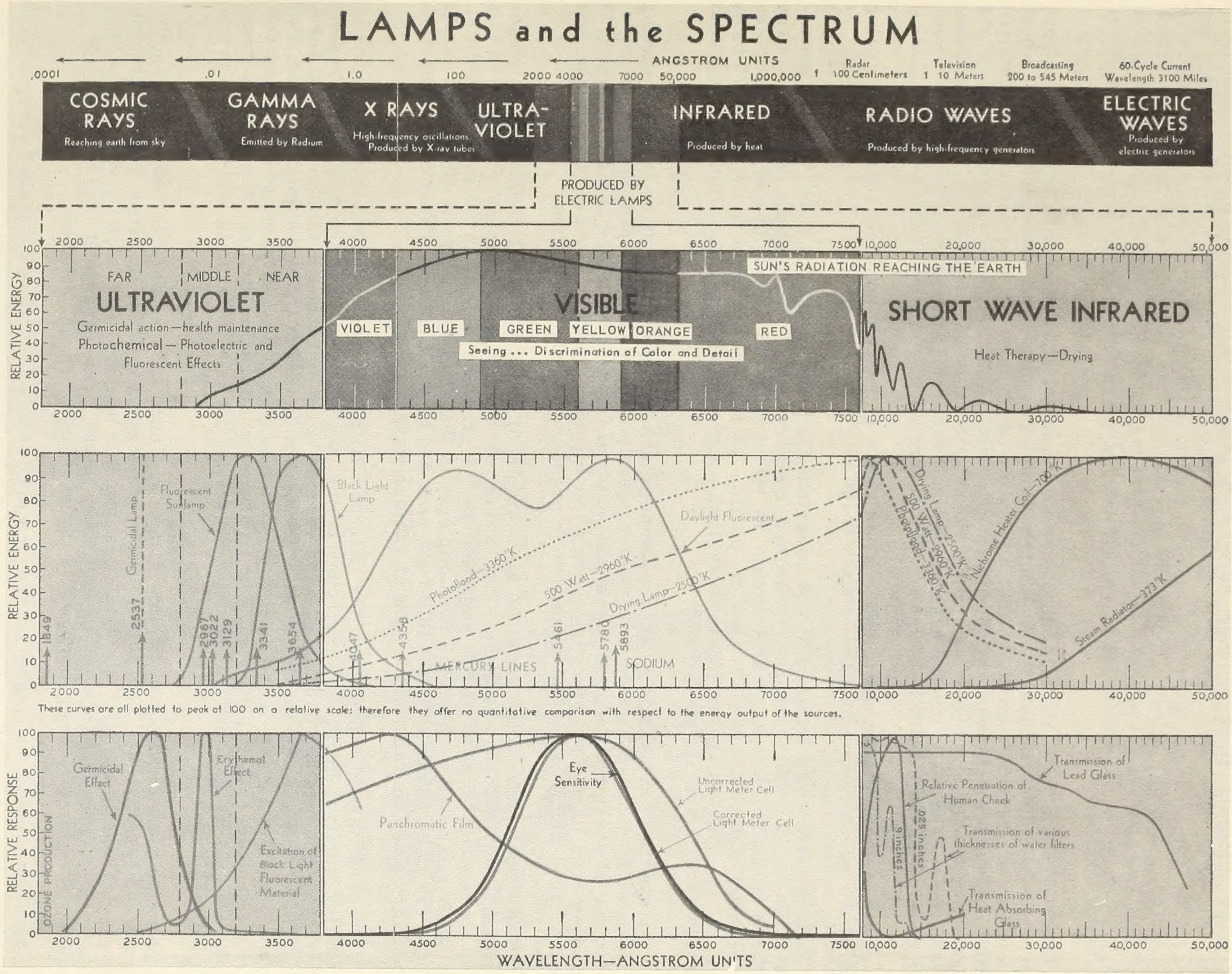

Source: Lamps and the Spectrum, General Electric LS-135, 4 pp. January 1956.
(Courtesy of General Electric Company.)

Many different light sources have been utilized in observing insect attraction to light. An open fire was probably the first, followed by the candle, kerosene lamp and lantern, acetylene lamp, gasoline lantern, carbon-filament electric lamp, and finally by the electric lamps utilized today. These include the incandescent using a tungsten-filament, and various gaseous discharge sources employing mercury and other gases and vapors such as argon, neon, and xenon. The fluorescent lamp is a mercury vapor discharge source.

Light from a fire, the candle, the kerosene lamp, and the lantern is a weak yellow. That from the first incandescent electric lamp, equipped with carbon filament, is also yellow but of greater intensity. Certain gasoline lanterns and the acetylene lamp provide white light with much less yellow and considerably more blue and violet. Likewise, the tungsten-filament lamp provides white light and, with special glass bulb, a limited amount of ultraviolet. The mercury and argon gaseous discharge lamps have been the most common sources of ultraviolet light used in our recent studies on insect attraction.

Incandescent, fluorescent, and certain other gaseous discharge sources are being used at the present time in insect survey traps in the United States.

The incandescent lamp, with its tungsten filament, is usually filled with an atmosphere of argon and nitrogen to retard evaporation of the filament. Relative energy radiated in the visible region is lowest in violet blue and highest in the red regardless of filament temperature. The major portion of the energy input to the lamp, 75 to 85 percent, is radiated in the infrared region. As previously indicated, limited ultraviolet is radiated with special glass bulbs.

The fluorescent lamp is a mercury vapor discharge source acting on light-generating phosphors. The lamp generates ultraviolet radiation at a wavelength of 2537 A. Phosphors, which are powders or chemicals, coat the inside of fluorescent lamps and transform 2537 radiation into longer wavelengths. A very low mercury vapor pressure, roughly one, one hundred-thousandth of normal atmospheric pressure is held in the tube.

The BL (black light) lamp is an example of converting 2537 radiation into longer wavelength ultraviolet radiation. The curve of the relative spectral emission of this lamp is shown because of the radiation in the green as well as in the near ultraviolet. The BLB lamp varies from the BL lamp only in that it is self-filtered with a red-purple bulb. This bulb absorbs the visible light radiated by the BL lamp. Other phosphors convert 2537 radiation into visible light of various wavelengths.

Mercury lamps other than the BL and BLB fluorescent have been used in insect attraction studies, because all mercury lamps supply radiation in the black-light region. Spectral output data are available on the various types and sizes in tabular form to serve as a guide in selecting the lamp with greatest radiation at the wavelength desired. Two lamps, the H100A4 and H400E1, are of particularly high near ultraviolet output and both have been used rather extensively in field insect attraction studies. The radiant power of the H400E1 is greatest in the near ultraviolet but is also large in violet, blue, green, and yellow.

Another lamp, the argon glow lamp, has been of considerable value in attracting the pink bollworm moth. This lamp, which consists of a mixture of gases, radiates mainly blue, violet, and in the near ultraviolet region. The spectral emission curve for this lamp indicates the predominance of its radiation in the near ultraviolet region. Radiation by the neon glow lamp on the other hand is in the yellow, orange, and red.

Mention should be made of the infrared radiation from a female Cecropia moth measured and published by Duane and Tyler in 1950. Quoting directly they report "apparently she radiated in a definite pattern in the region from 3 to 11 microns." This is in the infrared region and equivalent to 30,000 to 110,000 A. An answer to the authors' question "Is this radiation the attracting medium which guides the male moth through fog and darkness to his mate?" has not yet been given as far as can be determined.

Light traps were described in the literature at least 5 years before Edison's invention of the incandescent electric lamp with carbon filament in 1879. Because of this early development of light traps using light sources other than the electric lamp and probably because of lack of available electric service, light traps using electric lamps are not mentioned in the literature until after the start of the 20th century. Development of the tungsten-filament lamp in 1907 was followed almost immediately by specially designed light traps using it as the attractant.

For this discussion, light trap designs will be considered for two purposes: (1) Survey of insect emergence and abundance and (2) control of economic insects.

Traps designed particularly for survey purposes require selection of the attractant, positioning it in the trap, and design of the collecting device. The latter may be assumed to consist of two parts: (1) The lamp housing consisting of the lamp support, access opening or funnel to the killing or collecting chamber and, if used, trap roof, baffles and other accessories, and (2) the killing or collecting chamber.

Electric lamps are now generally used as the attractant, but selection of the specific lamp for a certain insect species still requires experimental determination in many cases. Several of the lamps, previously mentioned, have been available for the first time since World War II. Limited information is available on their attraction to individual species. Available information on wavelength and intensity of radiation in relation to attracting certain insects will be presented by two of my colleagues later on this program.

Capturing devices for light traps vary in design because of differences in flight habits of various insects. Baffles are desirable in a trap for strong-flying insects such as the hornworm moths, since they will strike the baffles and drop into the trap. With light flyers, such as mosquitoes, pink bollworm moths, and cigarette beetles, an electric fan may be desirable to draw the insects into the trap.

The killing or collecting chamber may be a screw-top glass jar of appropriate size, a quickly detachable metal container, or a screened bag or box. Use of the last is normally restricted to situations where live specimens are desired. Various poisons are used in the jar or container to quickly kill the insects. A discussion of the merits and disadvantages of each would be too lengthy to warrant inclusion here.

Several traps for attracting specific insects have been developed. The New Jersey mosquito trap was developed in approximately its present form in 1933. There were 205 of a modified type of this trap in use in California for mosquito survey work in 1957. The attractant is a 25-watt, inside-frosted, white, incandescent lamp. A 3/8-inch galvanized screen over the mouth of the tube prevents entry of large insects but permits mosquitoes and other small insects to enter. An electric fan just below this screen circulates air downward through a bronze screen wire cone at a velocity of 850 feet per minute. Insects are collected in the jar at the bottom.

A similar trap has been built according to Defense Department specifications for survey of mosquito populations. On the front of the black box is an automatic time switch.

Other survey traps were developed between 1928 and 1942 for certain insects including gnats, European corn borers, Noctuidae, fleas, Asiatic garden beetles, cigarette beetles, and leafhoppers. All of these traps use incandescent tungsten-filament lamps as attractants. But some studies are being made by the Stored Products Insects Branch, AMS, to determine the response of cigarette beetles to near ultraviolet radiation. A public patent was issued to W. O. Reed, USDA, on the original cigarette beetle trap.

Field tests of high-wattage mercury vapor lamps for European corn borer attraction were made in cooperation with the Indiana Station in 1949. A special cylindrical trap of 16-inch diameter and height, with 6- by 12-inch front opening was designed for this study. The design was eventually discarded because a smaller lamp and horizontal mounting appeared to be more suitable for survey work.

A megaphone-shape trap was developed in Indiana about 1950 to use a 100-watt mercury vapor lamp. It was the trap and lamp used in studies in Texas in 1952, when the pink bollworm moth was found to be attracted to a lamp.

Use of the BL lamp for survey purposes required a change in design because of the lamp length. Several such traps equipped with a 15-watt BL lamp were furnished to entomologists in several States and some may still be in use. Chief advantage was in low first cost but it was not entirely satisfactory because of its unidirectional design. We still list it as a useful survey trap.

A modified Minnesota European corn borer trap, equipped with two 15-watt BL lamps mounted horizontally as attractants, was developed in Iowa about 1954. This type was found to be much less effective in capturing European corn borer moths in 1958 than a trap without roof and one 15-watt BL lamp mounted vertically.

This roofless trap was developed primarily by J. P. Hollingsworth in Texas in 1953 for survey of cotton insects, particularly pink bollworm. One 15-watt BL lamp is the attractant. The metal collecting chamber is designed so that rain passes through and drains out of the bottom.

Three of these traps have been used in early pink bollworm survey studies in Texas: (1) trap with one 100-watt mercury vapor lamp (fig. 1); (2) unidirectional trap with one 15-watt BL lamp (fig. 2); and (3) trap with three 2-watt argon lamps (fig. 3).

A survey trap of the same design as one shown in figure 3 was used in late 1958 and 1959 by the Plant Pest Control Division in Arizona, Nevada, California, and Mexico for pink bollworm survey.

A modified type of this trap equipped with one 15-watt BL lamp has been supplied to entomologists for survey purposes in 24 States. Most of them are used for checking time of emergence and abundance of 10 common economic pests. Results reported are published weekly in the Cooperative Economic Insect Report. Considerable interest has been manifested recently by entomologists and engineers in the Middle West in the formulation and adoption of standards for: (1) Survey trap design, (2) trap installation, and (3) analysis of catches.

Light traps, designed to control insects, may be grouped into three types: Electric grid, suction, and mechanical. In general, light traps have not been recommended for control purposes, although they are used on small acreages of high-priced crops, around paper factories where night-flying insects must be controlled, at outdoor fruit stands, and around dairy stables and milkhouses.

The light trap with electric grid is flat or a hollow cylinder surrounding the lamp. All of the lantern type have used an incandescent lamp except that developed by Herms in California in 1935. The flat grid type has been used where BL lamps are used as the attractant (figure 4). Our field investigations on possible insect control with such traps have revealed serious clogging of the grids with heavy flights of European corn borer in cornfields or Heliothis zea in either cornfields or cottonfields. The majority of such traps have 3/8-inch grid spacing with impressed voltages of 3,500 to 4,500. Taylor experimented in Indiana during 1950 with a 1/2-inch grid spacing and higher grid voltages with less grid clogging. However, leakage through the supporting insulators developed at the higher voltages, thus creating a new problem. He published the requirements of a suitable insulator for a higher-voltage grid in 1951, but thus far no known changes have been made by manufacturers in grid voltage.

Experimental work at Oxford, N. C., in 1949, on hornworm attraction to ultraviolet lamps also disclosed shortcomings of the electric grid trap as a killing device. Hornworm moths attracted to the BL lamps were merely stunned by the grid and would

← Figure 1.--Light trap with one 100-watt mercury vapor lamp.

Figure 2.--Unidirectional light trap with one 15-watt BL lamp. →

← Figure 3.--Light trap with three 2-watt argon lamps.

Figure 4.--Electric grid insect control trap equipped with two 15-watt BL lamps.

fall to the ground, because they were too large to pass between the grids. Dr. O. A. Brown developed the collecting device which is located below the grid to capture the attracted moths. After some modifications in design, this mechanical type trap was manufactured without a grid and a fairly large number purchased in tobacco-growing areas. It has proven to be fairly successful in attracting and capturing hornworm moths. During the 3-year period, 1952-54, traps of this type were operated for surveys of time of emergence and abundance of tobacco and tomato hornworm moths at 13 locations in Florida, the Carolinas, Tennessee, Virginia, Maryland, New Jersey, and Connecticut by Federal and State entomologists. These two species are now reported in light-trap collections included in the Economic Insect Report. We are still trying to find a lamp that attracts equal numbers of both sexes of the Sexta species.

The suction-type light trap for control purposes differs from the electric-grid and mechanical types primarily in the use of a fan to draw in attracted insects. A few units of a large suction-type trap were produced by a manufacturer about 1950 for corn borer control. BL lamps were used as the attractant. The trap never has been produced for sale. Another suction-type trap of smaller size is being manufactured. A straight or circular BL lamp is used as the attractant. A trap of this type is available here for inspection.

While not a specific part of my topic, mention should be made of the development of an inverter which provides electric power at 110 volts from a 12-volt storage battery. One inverter was developed in 1959 by J. P. Hollingsworth, and was used in limited numbers by the Plant Pest Control Division, A.R.S., to provide energy to survey traps in areas where electric service was not readily accessible. Another type developed in Wisconsin was used in that State in 1959.

RELATION OF WAVELENGTH TO INSECT RESPONSE

Joe P. Hollingsworth[1]

INTRODUCTION

The purpose of this report is to present a review of previous work on the relation of wavelength of electromagnetic radiation to insect response[2] and to relate these results to recent findings by the Farm Electrification Research Branch Laboratory at College Station, Tex., on response characteristics of the pink bollworm moth (Pectinophora gossypiella (Saund.)).

THE ELECTROMAGNETIC SPECTRUM

The nature of all electromagnetic radiation in the spectral region under consideration (2,000 to 10,000,000 Angstrom units[3]) is the same in that the principles governing this radiation are based on the laws (1) that a moving electric field creates a magnetic field and (2) that a moving magnetic field creates an electric field. The created field at any instant is always in phase in time with its parent field, but is perpendicular to it in space (15).[4] The velocity or speed of this radiation when transmitted through space is that of light, or about 186,000 miles per second (3×10^{10} cm./sec.) and the various radiations differ only in frequency and wavelength. Since Velocity (a constant) = Frequency x Wavelength, then wavelength is an inverse function of frequency, i.e., as the frequency is increased, the wavelength decreases and vice versa. The study and understanding of the various regions of the entire electromagnetic spectrum are greatly simplified if one remembers that the entire wavelength scale represents the same type of radiant energy throughout and differs only in wavelength.

Light is defined as electromagnetic radiation to which the human organs of sight react and is generally considered to include the region between 390 and 770 mμ. Luckiesh (14) has defined various spectral ranges by names now commonly used as follows:

	Millimicron
Middle ultraviolet	200 to 300
Near ultraviolet	300 to 390
Violet	390 to 430
Blue	430 to 490
Green	490 to 550
Yellow	550 to 590
Orange	590 to 620
Red	620 to 770
Infrared	770 to 10×10^5

In general, the effect of radiation is directly proportional to its absorption, with chemical effects being of primary importance in the region below 390 mμ, and visual effects which allow discrimination of color and detail predominate in the region from 390 to 770 mμ. Heating effects are associated with wavelengths longer than 770 mμ (the infrared region) although all forms of radiant energy are eventually dissipated as heat.

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[2] "Response" as used in this report will refer to the measurable or observable reactions of insects when the insect is subject to irradiation by electromagnetic radiation.

[3] 10 Angstrom units = 10^{-7} cm. = 1 millimicron (mμ); therefore, the region of electromagnetic spectrum under consideration covers from 200 to 1,000,000 mμ. The latter nomenclature will be followed throughout this paper.

[4] Figure numbers in parentheses refer to Literature Cited at end of this paper.

REVIEW OF LITERATURE

Literature is voluminous on the subject of the effectiveness of various wavelengths of radiation for stimulating responses[5] in insects. Spectral response curves have been determined for a wide variety of adult and larval forms of insects and the region from 253.7 mμ to 700 mμ has been shown to contain those wavelengths most effective in producing responses. In general, three different techniques have been employed in determining these curves (17). These techniques include (1) training, individual responses, or field observations, (2) the use of electroretinograms (ERG), and (3) studies of group motor responses to radiant energy. Work on response determinations will be considered in order under these three general classifications.

Field Observations, Training, and Individual Response Studies: Probably because of lack of suitable energy sources, highly refined optical equipment and sensitive radiometry equipment (or failure to realize the importance of wavelength) most of the early work on spectral response determinations of insects was confined to observations of natural phototropic effects or to experiments involving training of individual insects. Weiss (22) points out that these early investigators apparently paid little attention to wavelength aspects of the problem and interpreted the behavior of the insects in terms of human color vision. He reviews this early work thoroughly and reports: "Sir John Lubbock established the fact that bees were apparently able to distinguish one color from another and could be trained to associate the finding of food with blue or orange colored papers. Auguste Forel accomplished the same thing with colored paper flowers. C. Hess projected a spectrum on a parallel-sided glass container that held imprisoned insects and observed that caterpillars and adults of the butterfly *Vanessa urticae*, and also bees, went to the yellow-green area. From these observations, Hess concluded that since totally color-blind persons see yellow-green as the brightest part of the spectrum, his insects were also totally color-blind. . . . K. Frisch trained an Asiatic species of honeybee to come to a given color for food and to pick out that color from among others when no food was present. . . . After conditioning the bees to various colors, Frisch concluded that bees could distinguish all colors except red and certain greens and that these colors appeared to them as darker or lighter grays, and that, therefore, their color vision was identical with that of partially color-blind persons. . . . Frank E. Lutz tested the colored papers used by Frisch and found that some of his greens and blues reflected ultraviolet, that his yellows and greens reflected blue and red, all of which invalidated Frisch's color scale for insects. . . . A. Kuhn and R. Pohl trained honeybees to come for food in a narrow trough illuminated by ultraviolet of wavelength 3650 A. After training, the food was removed and the entire spectrum was projected upon a sheet of white paper. Then the bees collected for the most part on the place subjected to wavelength 3650 A. Frank E. Lutz trained bees to come for food to a white card, reflecting ultraviolet wavelengths, and stingless bees to distinguish between ultraviolet patterns. . . . L. M. Bertholf, in an extensive study of the reactions of the honeybee to the spectrum visible to us, found that for this insect the spectrum extended from 4310 A., to at least 6770 A., the point of maximal stimulative effect being at about 5530 A. . . . He also worked with different wavelengths in the ultraviolet spectrum and found that the stimulating effect was greatest at 3650 A. for the honeybee."

Electroretinogram (ERG) Studies: The ERG is obtained by connecting electrodes near or directly to the optic nerves or by the use of contained electrolytes in contact with the surface of the eye into which electrodes can be inserted for picking up the induced potentials. The potentials developed when the eyes are subjected to intermittent or continuous radiation are transmitted to high gain electronic amplifiers and subsequently appear as traces on a recording oscilloscope or similar recording device. The curve or trace resulting from the external stimulations is called the electroretinogram. According to Jahn (12) spectral sensitivity curves can be obtained from the ERG by relating the magnitude of potential of any component of the ERG to the wavelength of incident radiation.

[5] See definition of response, footnote 2.

This technique was used in studies with the eyes of the dark-adapted grasshopper Melanoplus (4) and the silk moth Samia cecropia (13). When using equal intensities of incident energy, the wavelength with the greatest stimulation efficiency was found to be in the green region (530 mμ) with blue, violet, orange-red, and red (in order) of decreasingly less effectiveness. Ultraviolet wave bands were not included in these studies. Their general conclusions were that differences in ERG wave forms were due purely to intensity differences and that by properly adjusting the intensity of the different colors, the electrical response to different wave bands could be exactly matched. They also pointed out the similarity between the response curves obtained (a peak in the green region with sharp decline toward the red and a less sharp decline toward the violet) and the absorption curve of visual purple (rhodopsin) and the behavior curve of the fruitfly Drosophila.

Similar work was done with the king crab Limulus (15). The effect of various wavelengths of energy in the visual spectrum was evaluated for single visual sense cells. With light of equal energy content the strongest response was found to occur in the green region of the spectrum at 520 mμ. The response curve determined was symmetrical about the maximum of 520 mμ and, as the authors point out, closely resembles the visibility curve for human rod vision (dark-adapted eye). No Purkinje effect (shift in response toward the red end of the spectrum) could be observed even with intensities varying in ratios up to 100:1. These workers also concluded that the response did not vary qualitatively with wavelength because, by proper adjustment of incident energy levels, identical responses could be obtained for all of the different wavelengths tested.

Extensive examination of literature in this field has failed to reveal similar work with night flying insects. However, such information may evolve from work now under way by Mr. James Stanley, A.R.S., U.S.D.A., located at Virginia Polytechnic Institute, Blacksburg, Va. Mr. Stanley is currently studying the response characteristics of the tobacco hornworm moth (Protoparce sexta (Johan)) to equal energy, narrow wave band radiation by the use of kymographic equipment and techniques.[6]

Studies by the Group Motor Response Technique: Group motor response studies include laboratory and field determinations of the relative effectiveness of the various regions of the spectrum as evaluated by the numbers of insects of a particular species responding to a radiant energy source when energy from the source is presented to relatively large insect populations of either known or unknown exact magnitude. Methods employed and equipment used for making such studies have varied widely.

FIELD STUDIES

The electric insect trap has been the basic tool for field studies of this nature. Conclusions with regard to the effectiveness of various wavelengths have been made with reference to the spectral characteristics of the energy radiated by the lamps used in the traps.

Gui, et al. (11) made a rather comprehensive study of the relative attractiveness of different colored tungsten lamps in connection with research to determine lamps that were not attractive to insects. They found that all of the different colored lamps tested would attract insects to a greater or lesser degree and that the order of attractiveness (from greatest to lowest) was blue, white, yellow, and red. No ultraviolet lamps were included in these tests. Attractiveness of different colored incandescent lamps to certain species of mosquitoes was tested at Ft. Benning, Ga., in 1955 (1).

[6] Stanley, J. M. Monthly Activity Reports for 1959. (Copy on file Farm Electrification Research Branch, Agricultural Engineering Research Division, ARS, USDA, Plant Industry Station, Beltsville, Md.) (Unpublished) 1959.

Four New Jersey electric insect traps, each with a different colored tungsten lamp, served as mosquito samplers and were hung from a rotary trap stand. For most species of mosquitoes, a blue lamp was found to be most attractive, with a yellow lamp less attractive than the blue lamp and equal to or more attractive than a white lamp. These workers put forth the hypothesis that "the ultimate parts of lamp radiation end by blending with a certain blend being selectively attractive. Hence, perception is not confined to some narrow energy spectrum."

Taylor and Deay (18) conducted field wavelength tests in 1947. Sources emitting energy in five regions of the spectrum were used. The sources were a 8-watt germicidal lamp peaking at 253.7 mμ, a 100-watt mercury vapor lamp with filters so that the only emission was in the near ultraviolet range with a peak output at a wavelength of 365.4 mμ, a 100-watt mercury vapor lamp filtered to emit wavelengths in the vicinity of 435.7 mμ, a 100-watt mercury vapor lamp radiating through the principal mercury lines from 313.1 to 578 mμ, and a 15-watt fluorescent lamp peaking at 525 mμ. These sources were mounted in special collection traps so that insects which were attracted could be killed by cyanide gas. Primary emphasis was on catches of the European corn borer moth and it was found that the near ultraviolet source peaking at 365.4 mμ was the most effective attractant. Next, in order of decreasing effectiveness, was the bluish white (313.1 to 578 mμ), the blue (435.7 mμ), and the far ultraviolet (253.7 mμ), and the green fluorescent lamp (525 mμ). The authors indicated that no measurements were made of energy outputs of these sources and that differences in energy levels could have accounted for some of the differences in effectiveness.

Glick and Hollingsworth (7) established that mercury vapor and blacklight fluorescent lamps were highly attractive to moths of the pink bollworm. These lamps radiate strongly in the near ultraviolet range of the spectrum. Further studies on the attraction of pink bollworm moths (9) verified the attractiveness of lamps radiating in the near ultraviolet region. Low wattage near ultraviolet sources (2-watt argon glow lamps) were found to be nearly as attractive to pink bollworm moths as the higher wattage near ultraviolet lamps, but much less attractive to insects in general. These findings provided the basis for the design of special argon lamp electric insect traps for pink bollworm survey work.

Survey of the literature in this field fails to reveal information on any field wavelength studies with narrow wave band energy of equal physical intensities. Work of this nature was undertaken at College Station, Tex., in 1957 and 1958.[7] Special traps were designed for use with narrow band filters and provision was made for equalizing energy outputs by adjusting the filament voltage on special coiled filament tungsten lamps. Two trap designs were utilized, but neither design provided insect catches of sufficient magnitude for analysis of results. No reasonable explanation for the poor performance of these traps is obvious. Low intensity levels were thought to be a contributing factor but photometric measurements showed that at 365 mμ, for instance, the output was considerably higher than that obtained from 2-watt argon lamps. Single lamps of this type were quite effective attractants when operated at the same locations.

LABORATORY STUDIES

Laboratory investigations involving measurements of group motor responses as criteria for determining wavelength response characteristics of insects have been conducted by several workers and by a number of different methods.

Taylor and Deay (19) conducted laboratory studies on the response of the European corn borer moth. In these tests, one or more fluorescent lamps were placed at one end of a cylinder 15 feet long and 24 inches in diameter. A standard or check source was

[7] Hollingsworth, J. P. Annual Summary Reports for 1957 and 1958. Unpublished; (On file Farm Electrification Research Branch, Agricultural Engineering Research Division, Agricultural Research Service, U. S. Department of Agriculture, Plant Industry Station, Beltsville, Md.)

placed at the opposite end of the tunnel and consisted of one or more 15-watt blacklight fluorescent lamps. European corn borer moths were released at a center opening in the tunnel in groups of 10 to 20. Comparisons were made on the number of moths recovered in the vicinity of each lamp. Six types of fluorescent lamps with outputs, which covered various regions of the spectrum between 253.7 and 630 mμ, were tested. Taylor and Deay concluded that the wavelength of maximum attractiveness for the European corn borer moth at the intensity levels used in these studies is in the near ultraviolet region between 320 and 380 mμ.

Glick and Hollingsworth (8) in studies with pink bollworm moths used a similar technique. In these tests, a 15-watt blacklight fluorescent lamp was used as a standard of comparison and was placed at one end of a 30 by 30 inch tunnel, 24 feet in length. The lamp or lamps to be tested were operated at the opposite end of the tunnel. Pink bollworm moths were introduced into the center of the tunnel in groups ranging from 7 to over 400 and evaluation was based on the numbers recovered at each end of the tunnel. Tests were made of 28 lamps or combinations of lamps with outputs which covered various regions of the spectrum between 184.9 mμ (ozone lamp) and 1200 mμ (the infrared drying lamp). Of the several sources tested, only two proved to be more effective than the 15-watt blacklight fluorescent lamp--a 100-watt mercury vapor lamp equipped with a filter which transmitted primarily in the near ultraviolet region and a blacklight fluorescent lamp with a similar integral filter (General Electric Co. Type F15-T8/BLB).[8] Sex determinations were made of the moths responding to the near ultraviolet source and very little difference was noted in the male:female ratio.

Several laboratory wavelength studies by the group motor response method have been conducted in which very careful attention has been given to the quality and quantity of energy presented to the insects (6, 16, 19, 24, 25, 26, 27).

Weiss and his associates (24, 25, 26, 27) conducted extensive laboratory research with narrow wavelength bands of radiation of equal physical intensities. Ten wavebands, approximately 15 to 40 mμ wide, located at various points within the spectrum between 365 and 720 mμ were used in tests with over 50 different species of insects. The majority of the tests were with the adults of diurnal insects. The resulting response curves indicated that the stimulating efficiency increases only slightly from zero at 720 to 575 mμ, rises to a maximum at 492 mμ, declines to a low level at 464 mμ, and attains its peak at 365 mμ. Peterson and Haeussler (16) made rather elaborate laboratory tests of the response of the oriental peach moth and the codling moth. Tests with four rather broad wavelength bands in the visible region of the spectrum revealed that, when the intensities were approximately equal, the adults of both species preferred the blue and violet wavebands. Limited tests showed that the oriental peach moth was attracted to near ultraviolet sources but this region was not investigated thoroughly.

Ficht and Hienton (6) conducted laboratory studies on the effectiveness of ultraviolet radiation as an attractant for corn borer moths and were able to conclude that radiation below 320 mμ did not increase the efficiency of sources radiating strongly in the near ultraviolet region of the spectrum.

Stermer[9] and his associates made comprehensive laboratory studies of the spectral response characteristics of seven species of stored-product insects. Nine narrow wavelength bands (approximately 20 mμ in width) of radiation at equal physical intensities were used for the tests. These wavebands included 280.4 mμ in the ultraviolet and 600 mμ in the orange region of the spectrum. Four of the species used, the almond moth, the Angoumois grain moth, the lesser grain borer, and the red flour beetle preferred a wave band which peaked near 500 mμ in the green portion of the spectrum. A secondary peak of response was noted in the region between 334 and 365 mμ. One species, the Indian-meal moth, showed a peak response to wave bands between 334 and 365 mμ with a secondary

[8] Mention of companies or products in this paper does not imply recommendation or endorsement by the U. S. Department of Agriculture over others not mentioned.

[9] Stermer, R. A. The response of certain stored-product insects to various wavebands of electromagnetic radiation. 1958. (Unpublished master's thesis. Copy on file Tex. Agr. and Mech. Col., College Station, Tex.)

peak at approximately 500 mμ. The rice weevil showed no significant preference for the various wave bands and one species, the flat grain beetle, did not react in sufficient numbers to permit analysis. All species responded poorly to wave bands at 600 mμ. There was practically no response at 280.4 mμ. Figure 1 shows the relative response curves obtained for the rice weevil, the Indian-meal moth and the Angoumois grain moth. Further tests were conducted in which the energy levels were increased up to 11 times the arbitrary level used in the previous studies. It was found that the response reaction of all species of insects was increased significantly by an increase in intensity. For the almond moth, the region of peak response shifted from 546.1 mμ in the green to 365.4 mμ in the near ultraviolet.

Laboratory Studies of the Spectral Response of Pink Bollworm Moths

Laboratory investigations of the spectral response characteristics of pink bollworm moths were conducted during 1957, 1958, and 1959 by the Farm Electrification Research Laboratory, A.R.S., U.S.D.A., at College Station, Tex. Emphasis was given to work with this particular cotton insect pest as a result of work in 1952 which established that the pink bollworm moth was highly attracted to electric lamps with principal emissions in the near ultraviolet region of the spectrum (7). These investigations have been carried on in conjunction with work on the design and operation of improved survey type electric insect traps for aid in control efforts against this pest.

Three different test series have been completed at this time. For convenience of identification, these will be referred to as "Test Series I", "Test Series II", and "Intensity Studies" in the discussions which follow.

Test Series I: The objective of Test Series I was to determine the response of the pink bollworm moth to different narrow wavelength bands of equal energy radiation within the ultraviolet and visible regions of the spectrum. The test equipment included a 10" x 10" x 98" sheet metal tunnel (flat black interior) with provisions for compartmenting into five sections by means of sliding gates; a Bausch and Lomb grating monochromator adapted to utilize General Electric Co. Type H85-C3, H100-A4, and 18A/T10/4 lamps; General Electric Co. Type H100-BL4 lamp with filters for isolation of the 365.4 mercury line; a special photometer consisting essentially of a Varian Model G-10 recorder, a Type 1P28 multiplier type phototube, a high voltage D.C. power supply and appropriate circuitry. (See Stermer[10], for a complete description of the construction and calibration of this photometer.)

In this series of tests the response of pink bollworm moths to 18 different wavelength bands was determined by comparing the effectiveness of 365.4 mμ with the following wavelength bands:

Millimicron	Millimicron	Millimicron
280	385	515
303	405	546
313	420	560
340	434	578
350	460	600
365	486	625

The H100-BL 4 lamp was used with Corning glass filters Nos. 7380 and 5860 to provide the constant source of 365.4 mμ used as a standard of comparison. The 250 mm.

[10] See footnote 9.

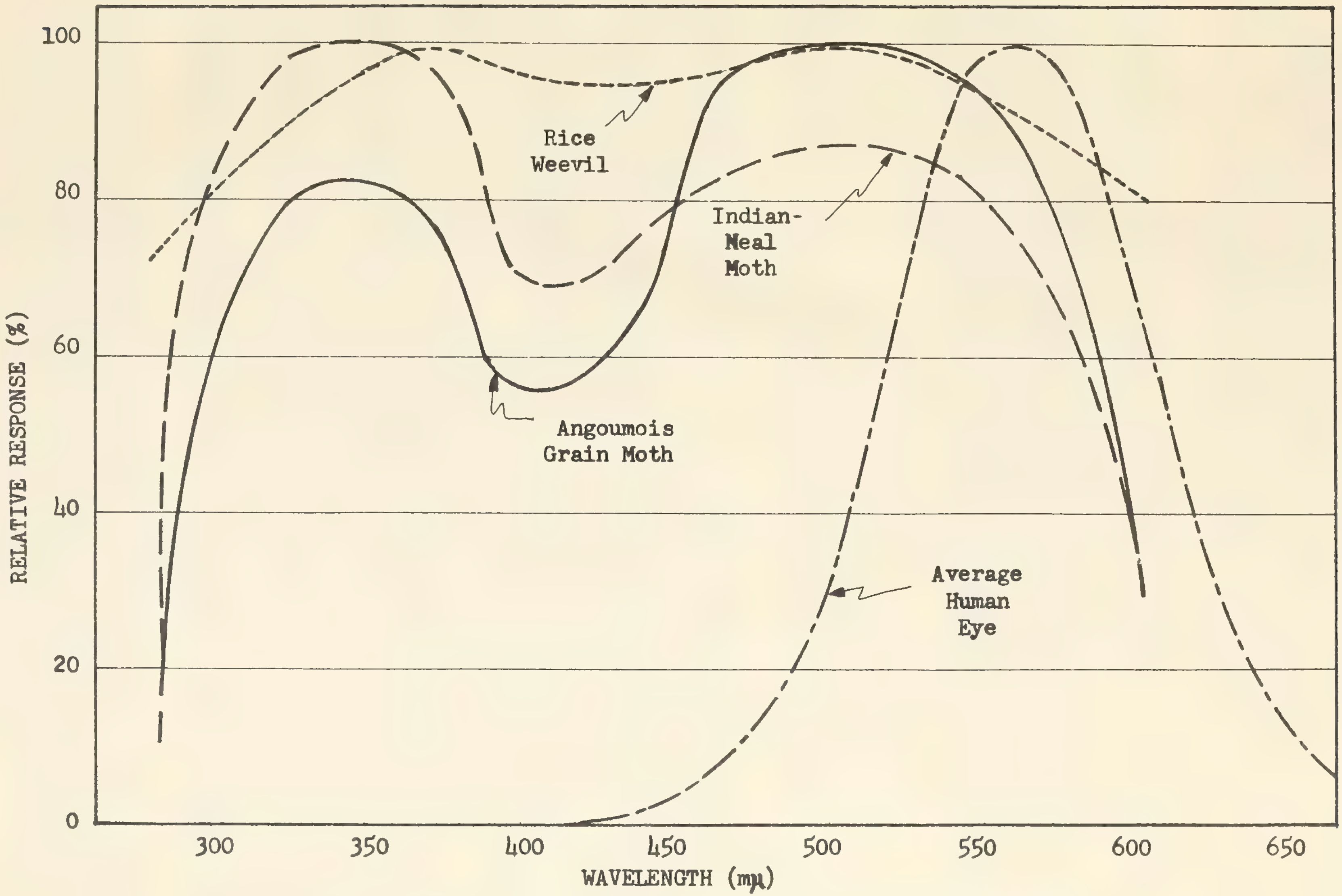

Figure 1.--Spectral response of three species of insects and the human eye (from Stermer, 1958).

focal length Bausch and Lomb grating monochromator with appropriate blocking filters and slits set at 0.5 mm. (this slit width gave a half-power bandwidth of radiation of 3.3 $m\mu$) was used on the opposite end of the tunnel to provide the test wavelengths. The radiation from these sources was presented to the insects by means of $3\frac{1}{2}$'' x $3\frac{1}{2}$'' quartz diffusers mounted at each end of the tunnel. Stray light was eliminated by means of sheet metal cones mounted between the diffusing plates and the sources.

Preliminary tests were conducted to determine testing techniques that would give reproducible results with a minimum of variation between tests. Use of a very low energy level was found to be desirable (probably due to dimensions of the test tunnel). The absolute value of this arbitrarily selected energy level was not determined, but measurement and calibration techniques permitted equalizing of the energy levels used at the various wavelengths. This equalization was based on the known spectral response characteristics of the multiplier phototube. It was also found that the moths were much more active during the afternoon and evening periods so all tests were initiated after 1100 hours. All tests were conducted with moths that had emerged from infested seed cotton some 3 to 4 days earlier. A minimum of 3 tests was conducted for each wavelength compared. This involved a total of 92 test runs and a total of 5,116 moths for the complete test series.

The following basic procedure was used for all tests:

1. A pre-selected energy level at 365.4 $m\mu$, as determined by the instrumentation, was applied to the quartz diffusing plate at one end of the tunnel.

2. The wavelength band to be used for comparison was applied at the opposite end of the tunnel at the same energy level.

3. Pink bollworm moths in groups of 10 to 152 (an average of 54 per test) introduced into the short center section of the tunnel were held in total darkness for a period of 5 minutes.

4. At the end of the 5-minute dark conditioning period, the tunnel partitions were removed, exposing the moths to the 365.4 radiation from one end of the tunnel and the test wavelength at the opposite end.

5. After 15 minutes' exposure to the two energy sources, partitions were inserted into the tunnel, dividing it into 5 compartments.

6. Heat was then applied to the tunnel by means of infrared drying lamps in order to kill the moths.

7. The numbers of moths of each sex in each of the 5 compartments were then determined.

8. An analysis of results was based on the numbers of moths found in the compartments adjacent to the ends of the tunnel.

Test Series II: In this series of tests, 10 wavelengths were selected for determination of comparative responses. Each wavelength was compared with every other wavelength, and two replications were made with each combination. This test procedure was recommended by statisticians of the Biometrical Services, ARS, who felt that such a test procedure would give more reliable data for analysis of response characteristics.

The following wavelengths were compared with each other in all possible combinations:

Millimicron	Millimicron
315	435
340	485
365	515
385	545
405	580

A Beckman Model DU spectrophotometer was modified for use as a monochromator to provide the various wavelengths at one end, and the Bausch and Lomb monochromator was used on the other end as in Test Series I. Slits of both monochromators were adjusted for a bandwidth of 3.3 mμ. It was found necessary to reduce the area of the quartz diffusing plates to $1\frac{1}{2}$'' x $1\frac{1}{2}$'' in order to accommodate the radiation pattern from the Beckman DU.

As in Test Series I, 3- and 4-day old moths were used and from 30 to 116 moths were used in each test (average number of 68 moths per test). Including reruns and tests under blackout conditions, a total of 131 tests were conducted, involving a total of 8,927 moths. All tests were initiated after 1,330 hours. The detailed test procedure for this test series was identical with the procedure as outlined in Test Series I.

Intensity Studies: The response curves obtained for Test Series I and II indicated that three wavelengths (365 mμ, 405 mμ, and 515 mμ) would be of principal interest in further work on the response of the pink bollworm since these were the wavelengths of maximum and minimum responses. The study on the effects of the use of higher intensity levels at these wavelengths was considered important, because other workers have put much emphasis on the importance of intensity effects on wavelength response. Preliminary tests were made in the small-test tunnel at higher intensity levels (higher than that used for Test Series I and II) but no reproducible results could be obtained. It was thought possible that the verified small size of the tunnel was the main factor contributing to this variation. This was verified by exploratory investigations in the larger test chamber used by Stermer[11] in his work with stored-products insects. This 4' x 6' x 14' chamber was made available for use in these tests and was found to be quite satisfactory for tests at the higher intensity levels. As in the tests of Series II, energy from the Bausch and Lomb monochromator and the Beckman DU spectrophotometer was presented to the insects through ground quartz diffusing plates. For this test series the image size was masked down to a size of $\frac{1}{2}$'' x 1''. Under these conditions it was found that the approximate minimum intensity level feasible for use was at a level 20 times greater than that used in previous tests in the small tunnel. An experiment was designed for comparison of 365, 405, and 515 mμ at intensity levels of 20, 40, and 80. The procedure for these tests was somewhat different from that used in Test Series I and II. The moths were given no dark conditioning period prior to exposure to the two sources of radiation. Also, owing to the large numbers of moths used per test, only one test--started late in the afternoon and continued until the following morning--was conducted each day. Insects attracted to the sources were collected in modified New Jersey mosquito traps.

This test series comprised 36 tests. Analysis of results was based on a total of 4,246 moths that responded to one or the other of the sources.

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[11] See footnote 9.

Results

Figure 2 shows the relative response curve obtained in Test Series I. For the energy levels and test conditions of this test series, the peak response occurs in the region between 486 and 546 mμ with a peak response indicated at approximately 515 mμ. Decreased response occurs in the vicinity of 415 mμ and then a secondary peak response occurs in the near ultraviolet region at about 365 mμ. There was very little response to wavelengths longer than 600 mμ or shorter than 300 mμ.

Figure 3 shows the relative response curve obtained in Test Series II. This curve is quite similar to the curve obtained in Test Series I and is noteworthy only because it indicates that equally reliable results can be obtained by either of the two test techniques when extremely low energy levels are used.

The results of the intensity studies are presented in graphic form in Figure 4. At the 20 energy level (20 times the level used in the wavelength tests of Series I and II) there was no shift in response characteristics, i.e., 515 mμ remained more attractive than 405 and 365 mμ and 365 mμ was more attractive than 405 mμ. At the 40 level, a shift occurred in the response characteristics and 365 mμ became more attractive than 515 and 405 mμ, with 405 mμ remaining the least attractive. Approximately the same relationship continued to exist at the 80 level with a slight increase noted for 405 mμ when compared with 365 mμ.

Discussion of Results

The spectral response curves obtained for pink bollworm moths in the ultraviolet and visible regions of the spectrum show that wavelengths in the green region (approximately 515 mμ) are the most attractive under the low energy irradiation conditions employed. The wavelength limits of effectiveness, the peaks of response, and the region of decreased response agree closely with certain insect response curves as determined by other workers, particularly Weiss and Stermer. The Angoumois grain moth exhibited very similar response characteristics to those obtained for the pink bollworm moth. The regions of principal interest, 515 mμ, 405 mμ, and 365 mμ, also coincide well with similar regions in many of the response curves determined by Weiss. At the low energy levels, the principal response occurs at 515 mμ for the pink bollworm moth, whereas Weiss found this region to be a secondary response peak for many of the insects that he tested.

Detailed wavelength tests have not been conducted with the pink bollworm at the higher energy levels. However, the results of the intensity tests with equal intensity narrow wavelengths bands centered at 365 mμ, 405 mμ, and 515 mμ indicate that the response peaks of 365 mμ and 515 mμ become equal at some energy level between 20 and 40 and that above this level the 365 mμ region is the principal response region with 515 mμ becoming less attractive. Recent work with the same wavelength bands at even higher energy levels (up to the 320 level, i.e., 16 times greater than 20 level) indicates that this relationship between wavelengths continues to exist at these higher levels. Thus, from the results of these tests, it appears that equal intensity wavelength tests at higher energy levels would yield a response curve for the pink bollworm moth nearly identical to those obtained by Stermer for the Indian-meal moth (and the Angoumois grain moth at high-energy levels.) Such curves would also correspond closely to the majority of the response curves determined by Weiss.

Sex determinations were made of all moths used in these tests. The response curve for the male and female moths was nearly identical.

No attempt will be made to analyze or explain the shift in peak response from the green at low energy levels to the near ultraviolet at increased energy levels. However,

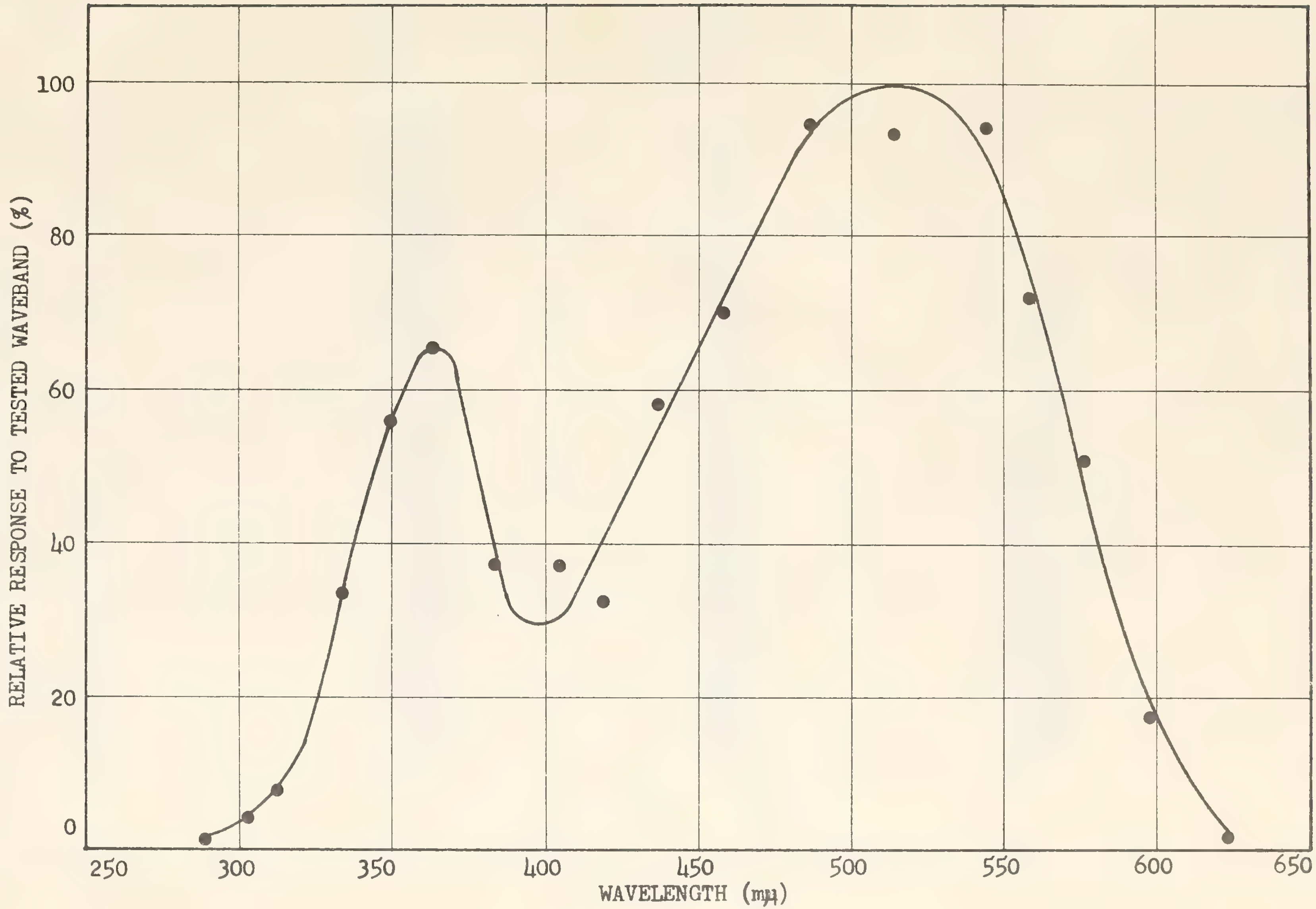

Figure 2. --Response of pink bollworm moths--test series I (365 mμ vs. other wavebands).

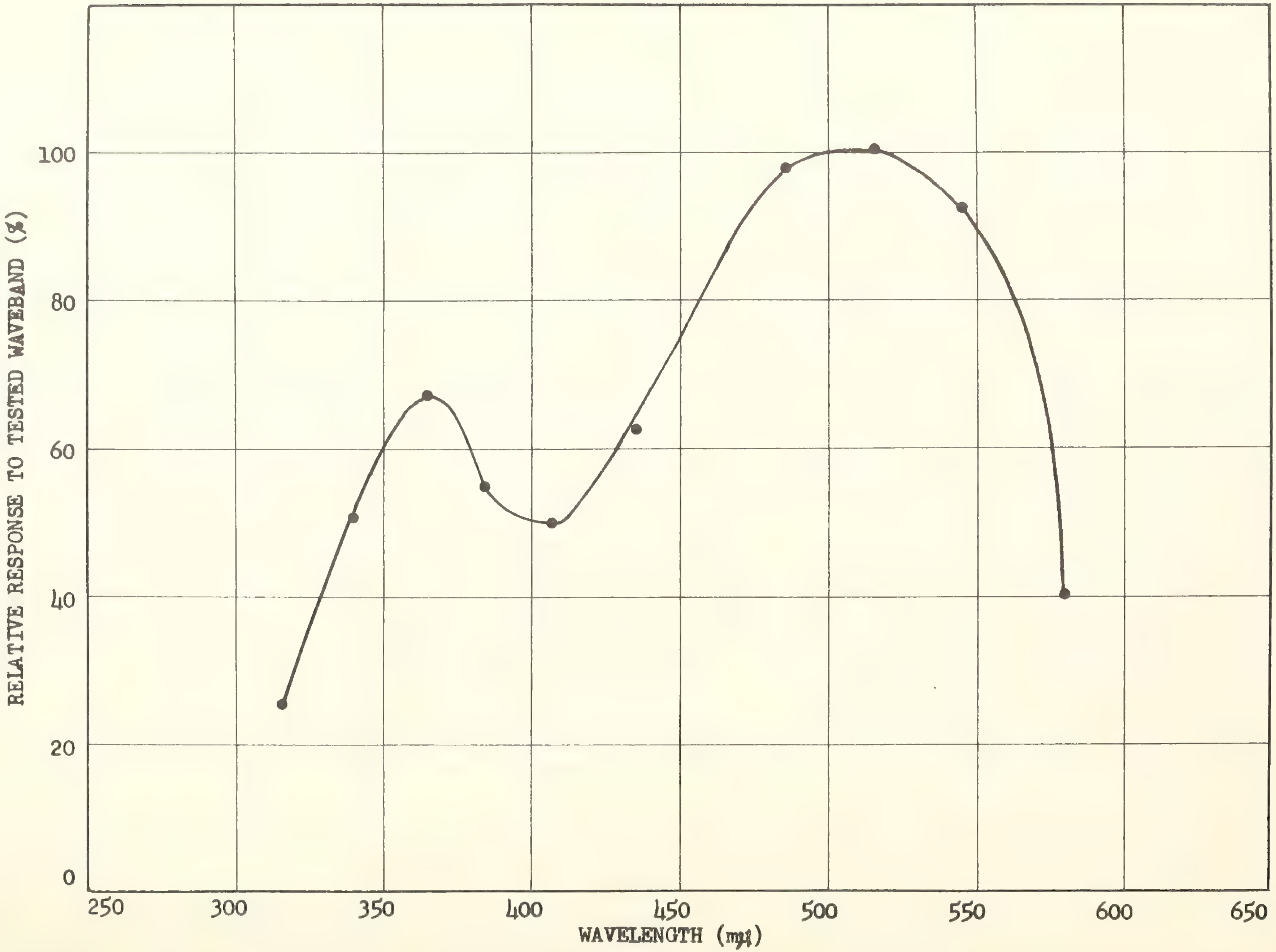

Figure 3. --Response of pink bollworm moths--test series II (each waveband vs. every other waveband).

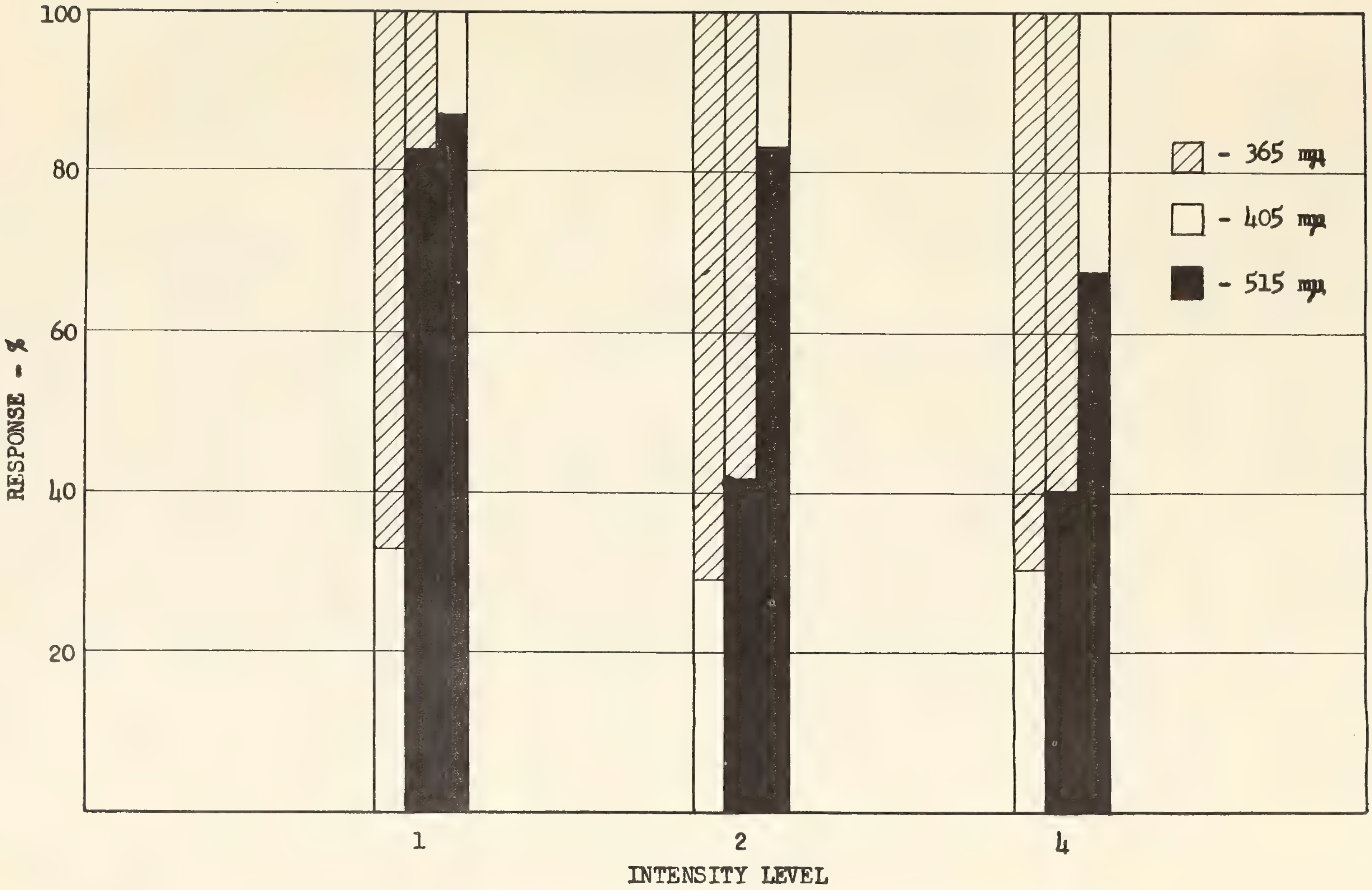

Figure 4. --Spectral response of pink bollworm moths and response curves of normal and aphakic human eyes.

as an aid to the consideration and understanding of the spectral sensitivity of the pink bollworm moth, Figure 5 shows a comparison of the pink bollworm response curves (low energy tests) with the sensitivity curves of the dark-adapted and light-adapted human eye and the dark-adapted aphakic eye. (Source: Curves for light-adapted eye and dark-adapted eye--Encyclopedia Britannica (5); Curve for aphakic eye--Calculated from Wald (21).)

As shown by these curves, the spectral sensitivity curves for the pink bollworm moth in the visible region corresponds closely to the sensitivity curve for the dark-adapted human eye since they both peak just above 500 mμ. This similarity has been pointed out by Dethier (17). He also points out that these curves are nearly identical to the absorption curve for the chemical rhodopsin or visual purple. (Note: Visual purple is defined as a purple-red pigment contained in the retinal rods of human eyes and those of most animals. It is quickly bleached by light. It is said to function in nocturnal vision and is abundant in animals that see well at night.)

It is also interesting to note that the aphakic human eye (eye with lens removed) shows greatly increased sensitivity in the near ultraviolet as compared to a human eye with the lens intact. Although scales used for the curves of Figure 5 do not permit emphasis of this increase, Wald (21) has measured sensitivity increases of as much as 1,000 for aphakic eyes. He relates that he has seen 60- and 70-year old aphakics read Snellen charts under conditions where he could not see the chart. Wald accounts for the increased sensitivity to near-ultraviolet by explaining that the lens of the average human eye strongly absorbs (or filters out) wavelengths shorter than about 400 mμ. These wavelengths therefore are not made available to the sensitive visual elements in a normal eye. He goes further to state "it has long been known that certain insects are highly sensitive to ultraviolet light. ... This need no longer be a matter of speculation for aphakic persons see very well in the ultraviolet".

The latent capabilities for human vision in the near ultraviolet appear to be further verified by the work of Crescitelli and Dartnell (3), who ran spectral absorption curves on the rhodopsin from recently extracted dark-adapted human eyes. Their work showed strong absorption by rhodopsin of wavelengths in the vicinity of 500 mμ, a decreased absorption at 440 mμ, and maximum absorption at 380 mμ. The work did not include wavelengths shorter than 380 mμ but the shape of the curves indicates a still higher maximum would be reached at 365 mμ.

Collins and Machado (2) related the response of the codling moth to the motility of the iris-pigment in its compound eyes. In studying its natural behavior the moth was found to be active only during the periods of pigment movement and it would respond to light only when completely or nearly completely dark-adapted. They found that radiation in the near ultraviolet region caused the dark-to-light pigment migration to start 5 to 10 minutes earlier and proceed to completion 20 minutes sooner than strong light from tungsten lamps and that the speed of pigment migration was related to the brightness of the source--the brighter source being more effective.

The implications of the foregoing results and comparisons seem to bear out the conclusions of Weiss (23) that "wavelength stimulus possesses both a physical and physiological intensity and that although the physical intensities of wavelengths may be equalized, the physiological intensities produce different effects due to the fact that the absorption of light by the primary photosensitive substance in the visual sense cells varies with wavelength".

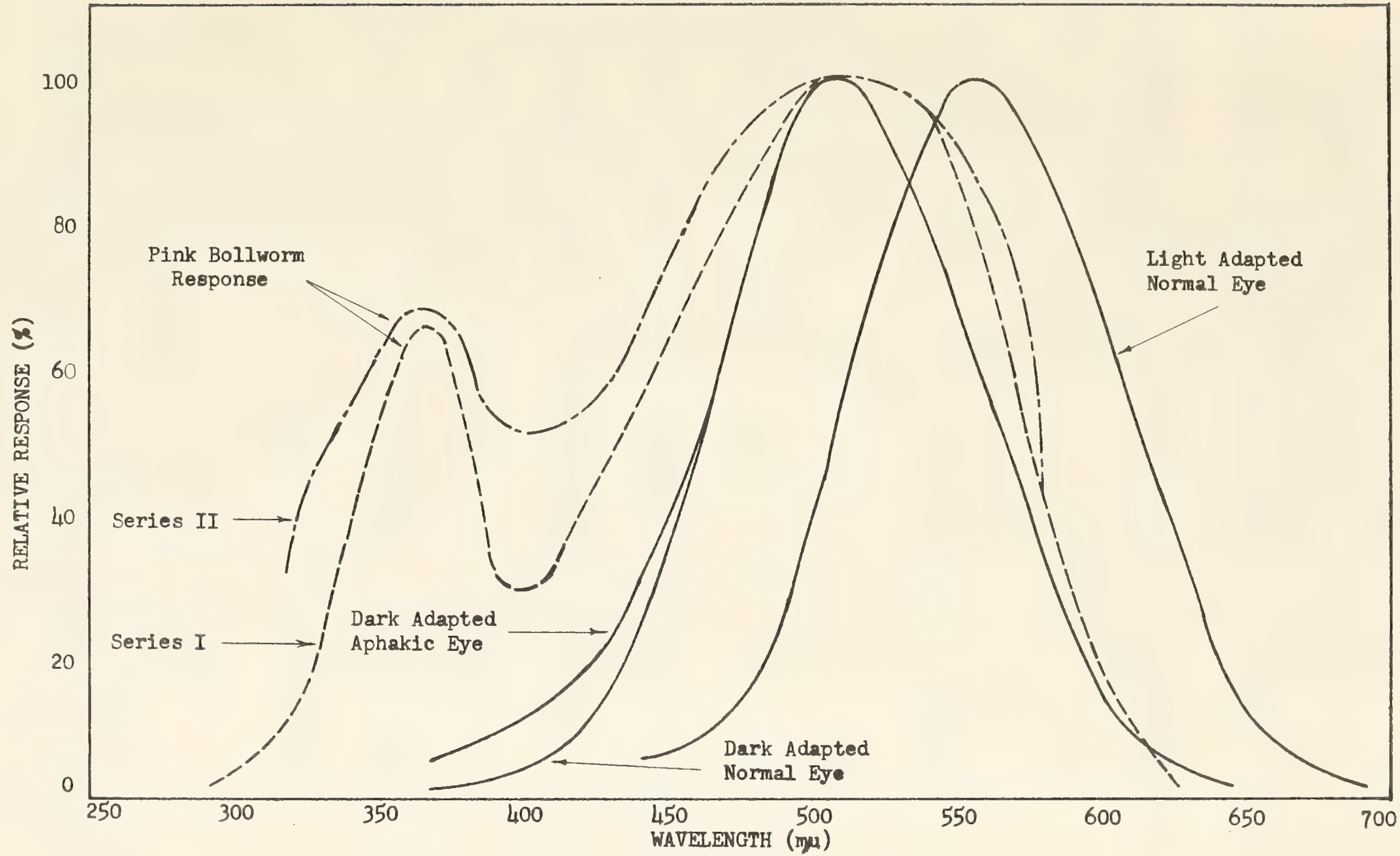

Figure 5. --Comparative response of pink bollworm moths to 365, 405, and 515 $m\mu$ at different intensity levels.

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RELATION OF LIGHT INTENSITY TO INSECT RESPONSE

J. G. Hartsock[1]

To discuss the effects of the various characteristics of light, one is almost inevitably faced with the necessity for defining terms to reduce the possibility of confusion. It seems especially appropriate to begin this discussion in that manner. Dr. Hienton has already defined light in terms of the wavelengths of radiant energy. It can also be defined on the basis of other characteristics: Illuminating engineers define light as "visually evaluated radiant energy." This visual evaluation depends upon the wavelength of the energy, its distribution in space, and its distribution in time.

Standard measurements have been adopted for the evaluation of these space and time distributions of light which are of interest in understanding the reactions of insects. Studies concerning the effects of light "intensity" on insect attractance have involved at least two of these different concepts. These standard measurements include:[2]

1. Quantity of light--the time-rate of light energy flow x time, a total energy measurement expressed in lumen-hours. Somewhat analogous to kw.-hr. of electrical energy.
2. Luminous flux--the time-rate of light energy flow, measured in lumens. One lumen is defined as the light emitted by a standard-candle source into a unit solid angle of space. Essentially a power measurement, analogous to watts.
3. Luminous intensity, also termed candlepower--a measurement applied only to point sources, also evaluating time-rate of light energy flow (luminous flux) through a unit solid angle, but in one given direction. The measurement is expressed in candles.
4. Photometric brightness or "brightness"--a more practical measurement of luminous intensity applied to sources of appreciable size. The luminous flux per unit of surface area of the source, expressed in candles per unit area, foot-lamberts (1 lumen/sq. ft.) or lamberts (1 lumen/sq. cm.).
5. Luminous flux density at a surface--luminous flux per unit of surface area, but applied as follows:
   a. Illumination--applies to surfaces receiving light energy, measured in foot-candles (1 lumen/sq. ft.).
   b. Luminous emittance--applies to a sizeable surface emitting light, measured in lumens/sq. ft.

The relations between candles, lumens, and foot-candles are shown in diagrammatic form in figure 1.

TYPES OF "INTENSITY INVESTIGATIONS"

On the basis of these definitions, investigations of the insect response to light "intensity" have involved both "luminous intensity" (or "photometric brightness") of the light sources used and the "luminous flux density" (or "illumination")produced in the surrounding space. From this confusion of concepts it is also easy to understand why workers concerned with illumination problems avoid using the term "intensity" and are careful to attach appropriate modifiers to clarify its meaning when used.

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[1] Agricultural Engineer, Farm Electrification Research Branch, Agricultural Engineering Research Division, U.S.D.A., Lafayette, Ind.

[2] Illuminating Engineering Society Lighting Handbook, 3rd. Edition, 1959.

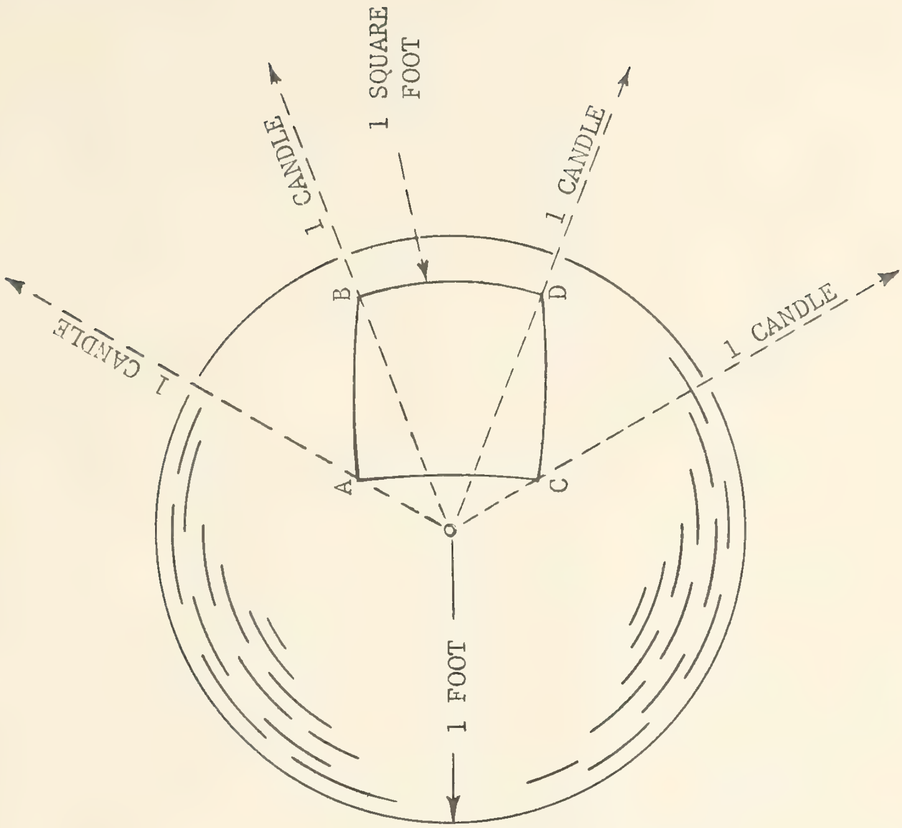

Figure 1.--Relationship between candles, lumens, and foot-candles.

A uniform point source (luminous intensity or candle-power 1 candle) is shown at the center of a sphere of 1 foot radius. It is assumed that the sphere is perfectly transparent (i.e., has 0 reflectance).

The illumination at any point on the sphere is 1 foot-candle (1 lumen per square foot).

The solid angle subtended by the area, A, B, C, D is 1 steradian. The flux density is therefore 1 lumen per steradian, which corresponds to a luminous intensity of 1 candle, as originally assumed.

The sphere has a total area of 12.57 (4TT) square feet, and there is a luminous flux of 1 lumen falling on each square foot. Thus the source provides a total of 12.57 lumens.

Because commercially available light sources of high "brightness" (or "luminous intensity") usually also produce high levels of "luminous flux density" (illumination) in the surrounding space, these two characteristics are difficult to separate in experimental practice. Consequently, many of the studies of insect attraction have involved a combination of variations in both "brightness" and "luminous flux density." Such comparisons clearly show the relative overall attractiveness of different lamps (of similar wavelength output), but do not indicate whether the differences in attractiveness are related to "brightness" or to "illumination." Examples of experiments of this sort are the comparisons of incandescent and mercury-vapor lamps of various wattages in early corn borer research. A portion of Dr. Pfrimmer's comparisons of various blacklight sources begun in 1955 are shown in table 1.

Many studies of the effects of differences in "luminous flux density" have been performed in which differences in "illumination" have been produced by using different numbers of similar lamps. The investigations of the attractiveness of different numbers of 15-watt BL fluorescent lamps, carried out both by Hollingsworth in Texas and by other research workers at Purdue, are typical of this type of study. Table 2 shows results of a study by Deay and Taylor.

TABLE 1.--Results of a typical experiment showing the overall attractiveness of different ultraviolet lamps resulting from differences in both "brightness" and "luminous flux density."

Species	Mercury-vapor 100-watt CH-4	BL 15-watt T-8	BLB 15-watt T-8
Agrius cingulatus (F.)	93	114	101
Agrotis malefida (Guen.)	38	252	139
Agrotis ypsilon (Rott.)	201	1,277	877
Celerio lineata (F.)	174	110	144
Estigmene acrea (Drury)	18	167	114
Feltia subterranea (F.)	198	1,810	1,042
Heliothis virescens (F.)	144	391	202
Heliothis zea (Boddie)	1,031	7,792	4,587
Laphygma exigua (Hbn.)	543	2,245	1,887
Laphygma frugiperda (A. & S.)	185	710	564
Loxostege similalis (Guen.)	2,941	7,259	5,975
Peridroma margaritosa (Haw.)	82	424	222
Prodenia ornithogalli (Guen.)	499	2,522	1,781
Protoparce quinquemaculata (Haw.)	51	40	38
Protoparce sexta (Johan.)	202	512	367
Pseudaletia unipuncta (Haw.)	2,119	4,328	3,069
Trichoplusia ni (Hbn.)	1,345	1,568	919

Source: Pfrimmer, 1955, "Catches of some species of Lepidoptera in three light traps at Tallulah, Louisiana."

Studies of the effect of "photometric brightness" could be devised through the use of sources of different brightness with appropriate areas exposed to create equal densities of luminous flux over the test area. This admittedly would be rather difficult, and the author is not aware of an instance in which it has been done. As a hypothetical case, to compare the insect attraction of the "brightness" of the H100-A4 mercury-vapor lamp (100-watt) with that of the 15T8 BL fluorescent lamp (15-watt), data on the relative blacklight ultraviolet outputs of these lamps indicate that about three 15T8 BL lamps would be required to give approximately the same "luminous flux" of 3650 A. radiation (here properly expressed in "fluorens," a special term used for blacklight measurements) as that of the H100-A4 lamp.

TABLE 2.--Results of a typical experiment showing the relative attractiveness of various levels of "luminous flux density."

Order and species	Number lamps and type[1]			Av. total catch per night (No.)
	1 - BL	3 - BL	4 - BL	
	Percentage of total catch			
Lepidoptera:				
Cabbage looper................	27.6	36.5	35.9	1,360
Fall armyworm.................	47.9	31.6	20.5	468
Garden webworm................	23.1	43.8	33.1	676
Bollworm......................	29.8	33.6	36.6	2,055
Miscellaneous.................	40.7	28.9	30.4	2,680
Coleoptera....................	32.4	27.2	40.4	10,196
Hemiptera.....................	15.8	36.2	48.0	1,987
Homoptera:				
Cicadellidae Spp..............	24.9	50.8	24.3	1,871
Trichoptera...................	32.8	21.0	46.2	10,550
Hymenoptera...................	7.7	73.9	18.4	520
Diptera.......................	34.9	28.4	36.7	854
All insects...................	31.2	29.2	39.6	33,217

[1] 15-watt fluorescent lamps.

Source: Hollingsworth, Texas A. & M. College Plantation, College Station, Tex., August 4-11, 1953.

BACKGROUND OF "INTENSITY" INVESTIGATIONS

Since the foregoing mention of a possibly untried scheme of study could be interpreted as an implied criticism of the investigators, the author wishes to state definitely that this is not the intention and hopes that a brief examination of the background of investigations of "intensity" will point out why. In the first place, the blacklight ultraviolet sources which are now accepted as being the most effective attractant for most nocturnal insects have been available for only a relatively short time and workers have found investigations of differences in attractance due to wavelength much more rewarding than those involving "intensity" during this period. It is also logical that investigations of the effects of "brightness" and "illumination" should follow determinations of attractive wavelengths.

Furthermore, studies involving "luminous flux density" and "brightness" become rather complex and are not readily done under field conditions. Characteristics of the output of lamps change with temperature, supply voltage, and duration of use, so it is difficult to maintain stable conditions in the field. Also, individual lamps and their associated circuit elements differ considerably in their output characteristics, so that calibration of components is usually necessary to keep experimental differences within

reasonable limits. Furthermore, instrumentation for evaluating "brightness" and "luminous flux density," especially of ultraviolet radiation, is not a readily available item of commerce. Suitable equipment that is both reasonable in cost and appropriate for field use is still being sought.

Actually, progress in research in the entomological field has occurred simultaneously with improvements in light sources and photoelectric measuring devices and with advancements in knowledge and standards concerning light measurement. Advances in the understanding of light phenomena have already resulted in better understanding of insect reactions studied by earlier investigators, as demonstrated by Von Frisch's theory [3] of the role of polarized light in the orientation of bees and ants. Satisfactory explanations of other known insect reactions will probably be found.

ESTABLISHED PRINCIPLES CONCERNING "INTENSITY"

Certain basic principles have been established by the studies conducted to date. It has been found, through comparisons of different lamps, that attraction increases with increases in both "brightness" and "luminous flux density" to a point and then diminishes; however, the increase in attraction is not proportional to the required increase in energy input. Figure 2 shows response obtained to "intensity" variations by Hollingsworth. Experiments with very "intense" sources, approaching that of the sun, show that activity of nocturnal insects ceases and day-flying insects become active. There also appear to be definite limits to the distance from which insects can be attracted to any light source.

This pattern of diminishing response to increases in "brightness" and "luminous flux density" is fundamentally related to efficient use of input power; naturally the

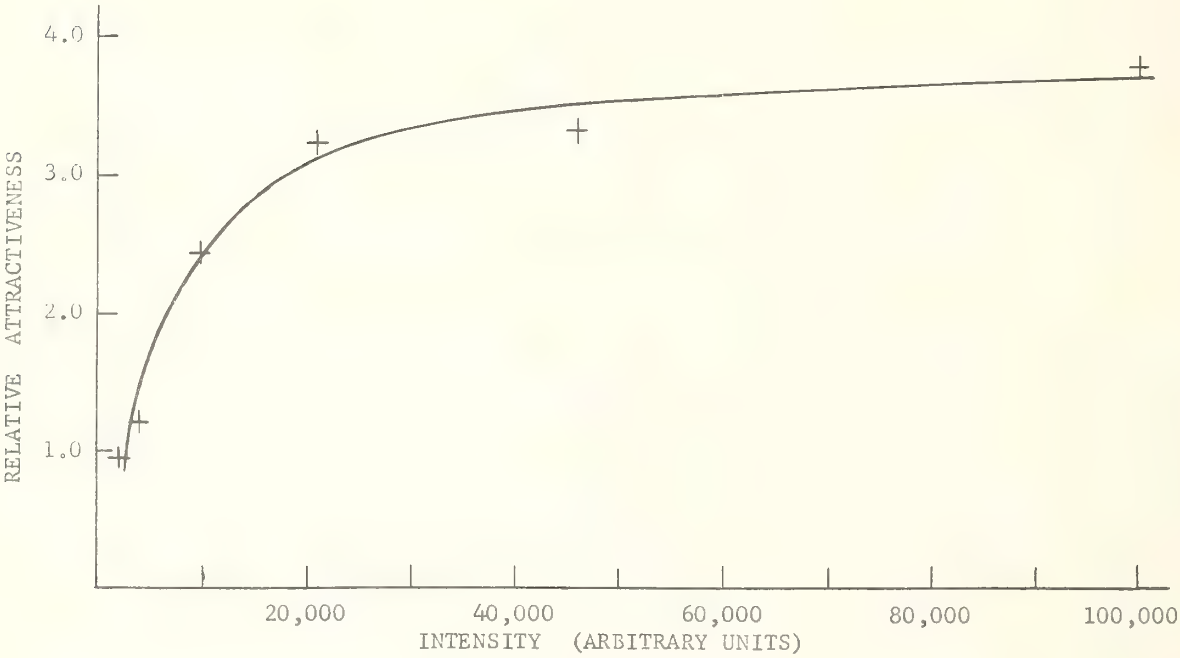

Figure 2. --Response of Microlepidoptera to white light of various intensities.

[3] Frisch, Karl von, Bees, Their Vision, Chemical Senses, and Language, Cornell University Press, 1956.

maximum attraction per watt of input would be desired. Consider a source radiating in all directions at unit input power to which insects are attracted from unit distance. If a change in input power is assumed to give a proportional change in light output (never achieved), then, by the inverse-square law of radiation, doubling the input power should increase the distance from which insects are attracted by a factor of the square-root of 2 (= 1.41) and the potential insect catch should be similarly increased. Thus, to catch the same proportion of the insect population at all levels of input power it is necessary that the catch vary as the square-root of the change in power input. This does not happen. Therefore, power is more efficiently used by distributing several low-power installations over an area than by concentrating an equal input in a single source.

The efficient use of power is of special importance where operations are carried on in isolated locations by use of storage batteries.

It is also known that the relative attractiveness of lamps of different "intensity" is not the same when the lamps are placed in competition with each other at relatively close distances as it is when the lamps are isolated from each other. When a large lamp and a small lamp are placed close together, the small lamp usually attracts a much smaller comparative catch than will be the case if the two are placed out of sight of each other.

Two other fundamentals are dictated by the difference between the concepts of "brightness" and "luminous flux density." "Brightness" of a source is affected only by changing the amount of luminous flux emitted from its radiant body. Incandescent and mercury-vapor lamps increase in "brightness" with increasing wattage ratings, but not in direct proportion to the wattage increase. Fluorescent lamps, which increase in physical size in almost direct proportion to their wattage rating, are of relatively the same "brightness" in all sizes. "Brightness" of either type of lamp is affected by changing the lamp current. Taylor[4] found in 1956 that doubling lamp current of 15-watt BL lamps increased ultraviolet output approximately 80 percent.

"Luminous flux density" is affected by anything which increases the total radiant energy flux through space. Thus, different "illumination" levels can be obtained by using multiples of similar lamps without altering source brightness. On the other hand, "illumination" may or may not be altered by changing the "brightness" of the source, depending upon the accompanying change in physical size of the source.

PRACTICAL CONSIDERATIONS CONCERNING "INTENSITY"

As the result of field experience and the considerations of most efficient use of input power previously mentioned, low-wattage ultraviolet sources are becoming generally accepted as attractants instead of high-wattage mercury-vapor lamps. Fluorescent BL lamps are widely used as general insect attractants and these are particularly efficient sources of 3650 A. radiation because of the conversion action of their phosphor. Specialized traps for the pink bollworm are using argon glow lamps, which are also low-wattage sources.

In insect survey operations two diametrically opposed needs are becoming apparent. Fluorescent BL lamps of the 15-watt size have been widely used for routine survey operations, particularly of insect migrations. Survey entomologists have long been troubled by the fact that these traps provide catches that are too large for adequate analysis by available personnel. Consequently, considerable consideration has been given to using a smaller lamp if the smaller catch from a lamp proves to be equally representative. On the other hand, in survey work to detect small populations of new or particularly undesirable insects, or in attempts to control insect damage, the

[4] Taylor, John G., Annual Report, Line Project AE d1-2, 1956, Farm Electrification Research Laboratory, AERD, USDA. (Unpublished).

maximum attraction which is economically feasible is desired. It appears that different equipment will need to be provided for these two objectives.

In development of light traps for use in isolated locations where efficient use of input power is essential, agreement is needed concerning the smallest lamp size giving a sufficiently representative catch.

ADDITIONAL FUNDAMENTAL INFORMATION NEEDED

In considering the need for additional information concerning the effects of "intensity" on insect attraction, it is obvious that more information is needed about the respective effects of "brightness" and "luminous flux density." Such investigations would undoubtedly have to be initiated as laboratory studies of specific insect reactions with evaluation of the characteristics of the light environment required to initiate them. If the fundamental reactions of attraction can be determined in this manner, then it should be possible to translate these findings into field techniques to achieve greater attraction.

Further investigation of the effect of the physical size of light sources would seem to offer possibilities for increasing attraction. From present knowledge of the vision of insects through their compound eyes it appears logical that source size, as well as light characteristics, would affect attractance.

There is also evidence of repulsion and immobilization[5] of insects from the effects of light and the causes of these reactions should be more clearly related to factors of the light environment.

It is hoped that the foregoing has made it clear that the relations of insect attraction to "intensity" of light are by no means fully understood.

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[5] Wigglesworth, V. B., The Principles of Insect Physiology, E. P. Dutton & Co., New York, 4th. Edition, pp. 134-159, 192-206. 1950.

SECTION II--INSECTS AND THEIR RELATIONSHIP TO LIGHT

WHAT INSECTS ARE POSITIVELY PHOTOSENSITIVE

[SUMMARY]

P. W. Oman[1]

Consideration is limited to the reaction of insect populations to induced electromagnetic radiation under natural conditions. The literature review upon which this paper is based is far from exhaustive.

There appears to be no simple, uncomplicated answer to the question of what insects are attracted to induced light. Whether or not an insect exhibits a positive response depends upon various circumstances, some of which concern the insect itself, some of which depend upon its environment, and some that depend upon the nature of the induced light. Several of these factors are to be discussed by others during this seminar. There are thousands of kinds that respond to light, in varying degrees, under certain favorable circumstances.

Only in a very general way are there correlations between phylogenetic position of a species and the inclination of its representatives to respond to induced light in a positive fashion. Certain orders--Thysanura, Mallophaga, Anoplura, Zoraptera, and Odonata--apparently lack species that exhibit a positive response. Other orders--Collembola, Isoptera, Mecoptera, Dermaptera, Psocoptera, Thysanoptera, and Siphonaptera--are composed largely of species that are not positively photosensitive, yet contain some members that are readily attracted. More critical exploration among representatives of these orders, with different types of light, may considerably alter our ideas.

The bulk of the photopositive species of insects belong to the orders Ephemeroptera, Neuroptera, Orthoptera, Hemiptera, Coleoptera, Trichoptera, Lepidoptera, Diptera, and Hymenoptera. In general, diurnal species are not attracted to induced light. The great majority of the species that show a marked positive response to light are nocturnal, or carry on some function essential to species survival at night or at dusk or dawn. Examples of these essential activities are emergence to the adult stage, mating, oviposition, feeding, and dispersal flights. However, numerous nocturnal species are not positively photosensitive.

Well-known pest species among the Lepidoptera, the adults of which may be attracted to light, are the codling moth, oriental fruit moth, corn earworm, various cutworms, fall armyworm, cabbage looper, European corn borer, pink bollworm, and others. Many respond only to certain wavelengths of light, and most show definite time peaks of nocturnal activity. Lepidopterous families containing numerous photopositive species are Noctuidae, Notodontidae, Sphingidae, Arctiidae, and Geometridae, as well as many Microlepidoptera of various families.

The Scarabaeidae and Staphylinidae, among the beetles, contain many species that are attracted to light. However, the Japanese beetle, a diurnal scarab, is not so attracted. The Asiatic garden beetle and the European chafer, both introduced scarabs, are strongly attracted to light, although the European chafer apparently responds to induced light secondarily, after being stimulated by decreasing light intensity to swarm for mating purposes.

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In the Diptera most of the positively photosensitive species occur in the Nematocera, particularly in the Chironomidae, Ceratopogonidae, and Culicidae (sens. lat.). Among the Brachycera, members of the family Pyrogotidae and the tribe Ormiini of the Tachinidae are attracted to lights. These flies are parasitic on nocturnal insects and are usually active at dusk or at night. Other photopositive Brachycera occur in the Empidae, Lonchopteridae, and Sphaeroceridae.

In the Hemiptera the sternorrhynchous Homoptera are little attracted by induced light, although aphids may be more strongly photopositive than has been suspected. Of the auchenorrhynchous Homoptera the leafhoppers and fulgoroids, particularly the former, contain many species that are positively photosensitive. Among the terrestrial Heteroptera, several lygaeids, mirids, and cydnids are strongly attracted to light, as are most corixids and some other aquatic species. Usually males of the terrestrial Hemiptera respond more frequently than females.

Present evidence regarding the attraction of insects to light is unsatisfactory for a critical appraisal of the phenomenon. Most published references, particularly the older ones, give little information except that certain species came to light. Knowledge of other species present in the area, but not attracted, is almost invariably lacking, as is information regarding population levels of species that show positive responses. With few exceptions, the optimum conditions for attracting a given species of insect are not known.

HOW INSECTS ARE PHOTOSENSITIVE

[SUMMARY]

Roy J. Barker [1]

Insect vision is basic to orientation, movement, and consequently insect environment. Nevertheless, entomologists have left mostly to others the problems of understanding insect vision. Basic research is needed before success can be expected even from light traps. For example, intensity is usually measured in units (such as foot-candles) based on "normal human observers," which have no physiological meaning when applied to insects.

General receptors such as simple dermal cells that respond to light probably occur in insects. The eye spot in maggots has some elements of eyes but no iris pigment. Grasshoppers have many areas of cuticle modified evidently to function as heat detectors.

Simple eyes exhibit extensive variation in morphology. Images are in focus over a wide depth of field, but such images are not necessarily used by the insect. The receptor morphology of insects involves a layer of visual cells that is perpendicular to the lens image, not parallel as in mammals.

Compound eyes contain packed rods of rhobdomeres stacked radially. In Drosophila each 17 by 100 micron ommatidia contains 17 rhobdomeres. Compound eyes contain from 1 to 28,000 ommatidia. Some iris pigment occurs even inside of the visual cells. The presence of numerous mitochondria suggests high metabolism in the visual cells.

The lens diameter as well as the angle between neighboring ommatidia seems to limit the resolving power of insect eyes. The corneal lens is transparent to ultraviolet

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except during molts; a molting insect is nearly blind. The cone of the eye must provide a clear path of a proper refractive index to conduct light from the lens to the rhobdomere. The iris pigment functions to produce a super-position or an apposition image depending upon the intensity of light. The identified pigments are related to pteridines and many are fluorescent. Perhaps pteridines convert ultraviolet into visible light in insects. The color of the reflecting pigment seems to have a secondary effect on spectral response.

A pigment must do more than simply bleach in light to be a visual pigment. Retinene-1 has been isolated from honeybees. Since most insects do not require dietary vitamin A, the precursors of insect retinene are unknown. Rhodopsin consists of opsin plus retinene. Insect opsin is uniquely water soluble. Spectral response curves for insects indicate that rhodopsin and another visual mechanism are involved. The absorption of some photo-labile pteridines from Drosophila show partial correlation to the spectral response of the strain tested. The complex biochemical reactions of rhodopsin initiated by light occur in microseconds. In converting light to chemical energy, configurational changes of opsin apparently opens a "condensor" of about 1,200 molecules in the stacked rods. One quantum of light can thus release an electric impulse sufficient to depolarize a sense cell with a utilization efficiency of nearly 5 percent.

Electroretinograms of optic nerves can give a quantitative measure of responses to spectra, polarization, and form. Simple and compound eyes have similar response patterns. When individual ommatidia are tested, synchronous discharges show interaction between the visual units. The frequency of nerve impulses depends upon intensity and is modified by temperature, exposure time, adaptation, and other factors.

Orientation mechanisms involve intensity discrimination, acuity, form perception, polarization, and color distinction. Flight periods are closely related to a critical intensity because insect vision adapts to dark by a sensitivity increase of only 100 times; in man sensitivity increases 10 million times. Insects fly during periods of iris pigment movement because these are the times they can see. Most insects have better vertical than horizontal acuity because the ommatidial angles are smaller vertically. The angle of discrimination and acuity of movement is about 1 percent of that in man. Some fast-flying insects possess diphasic electroretinograms and can distinguish 250 light flickers per second. Other insects have flicker vision more like man (40-50/sec.) and a higher absolute sensitivity to light. This may be related to peculiarities of (insect opsin. In a form perception, the most stimulating patterns match ommatidial angles 1°-3°). Moving objects are more attractive; more ommatidia are stimulated. Flickering light is more stimulating than continuous light. (For some insects fluorescent lights are flickering.)

The important factor in form perception is not shape, but how many ommatidia are stimulated. Discrimination of polarization could result from lens reflection of peripheral vision since polarized light reflects selectively. Guidance by polarized light is conceivably guidance by the reflection pattern of the environment and needs no specialized receptor. Color distinction is probably a function of differences in the activation energy of opsin molecules. Pigment analyses of insects trapped at different colors could determine whether insects see ultraviolet because of iris pigment fluorescence or because of the uniqueness of insect opsin. Acuity at some colors is affected by iris pigment color in a manner analogous to wearing sunglasses.

Loeb's theory of symmetrical stimulation guiding insects to a light source is unnecessary, because ommatidia are of unequal sensitivity. In keeping the light where it seems brightest, an insect maintains a constant angle to the source. If this angle is less than 90°, the insect spirals toward the light, and this occurs even with only one eye functioning.

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RELATION OF ENVIRONMENT TO PHOTOSENSITIVITY OF INSECTS

[SUMMARY]

W. C. Cook[1]

A great deal of work has been done on the relation of environmental factors to photosensitivity of insects, but much of this is purely observational and qualitative. Few quantitative studies are available in which the various factors have been isolated and studied. One of the best general studies is that of Stirrett (1938)[2] on the European corn borer in Ontario, in which he compares his own studies with previous work. The factors which he listed were temperature, humidity, wind, atmospheric pressure, rainstorms, atmospheric electricity, cloudiness, lunar periodicity, fog or mist, and dew and guttation.

TEMPERATURE. Anyone who has watched a light trap in operation has been impressed by the irregularity of the captures. For a few seconds or minutes the insects will literally come in clouds, and then stop as suddenly as they started. This will be repeated again and again. The writer has exposed sensitive thermometers while watching such catches, and had found that a change in temperature of 1° or 2° F. will cause this fluctuation. A general cooling will be interrupted by a slightly warmer breath of air for a few minutes, and then followed by further cooling. Few thermographs respond fast enough to catch these changes.

Stirrett, in his review of temperature and flight, mentioned that most of those who studied temperature found a positive correlation between flight and temperature. C. B. Williams (1935) operated a light trap at Rothamsted, England, for several years, in which a series of killing bottles made it possible to divide the night's catch into 8 time-interval lots. He found the highest catches associated with nights having a high minimum temperature and a flat temperature gradient from dusk to dawn. Poor catches were associated with steeper temperature gradients.

Dirks (1937), working in the cool climate of Maine, found very low catches at average night temperatures of 40° to 42° F., and his highest catches were at average temperatures above 58° F.

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[2] For references in this paper, see section on Bibliography of Insects and Light at end of this publication.

Lawson, Chamberlin, and York (1951) showed that flights of the beet leafhopper ceased at temperatures close to 58° F. This leafhopper is normally regarded as a daytime flier, but on hot nights when the temperature was 70° near midnight, large numbers came into light traps at the laboratory, Modesto, Calif. On such nights other day-flying insects such as grasshoppers and butterflies were also captured. Rockwood has also recorded night flights of diurnal insects under similar conditions.

To obtain some fresh data on the effects of temperature on the flight of noctuid moths to lights, the writer took records for 5 years from a stationary ultraviolet light trap (20-watt fluorescent BL bulb) at the laboratory, Walla Walla, Wash. To smooth out the large seasonal variations a 5-day running average was used and the daily catches computed as percentages of that average. The midnight temperature reading from a thermograph about 100 yards away, in a standard shelter, was used. Tabulating these catches against the midnight temperatures, the index catch increased from 62 percent between 36° and 45° F. to over 103 percent between 56° and 65°, with a decrease at higher temperatures. This would indicate a rather low temperature optimum for noctuid flight.

Because of the effects of slight changes in temperature on flight observed in the field, a further tabulation was made in which the index catches were tabulated against the change in temperature from the preceding night (midnight temperatures). No statistical analysis has been made, but about 500 nights were included in the tabulation, and all points between -14° and 12° are based on 10 or more nights. A freehand line drawn through the averages for 2° intervals indicates a change of somewhat more than 2 percent in the catch for each change of 1° in midnight temperature.

In making the above tabulation it appeared that a second night of increasing or decreasing temperature had less effect on the catch than the first night. This might indicate, for rising temperature, the possible attrition of the supply of photosensitive moths from the first warm night. Causes might be local population shifts or changes in the rate of emergence from the pupal stage. The same records indicate that very hot nights were unfavorable for noctuid flight, but the traps captured large numbers of midges, caddis flies, small beetles, and leafhoppers.

HUMIDITY. Stirrett (1938) showed that 89 percent of the moths of the European corn borer flew at saturation deficits between 0 and 6 mm. His data do not indicate, however, whether such nights were customary or rare, but it may be assumed that many such nights occurred in southern Ontario. My own early work in Minnesota and Montana indicated that there might be an optimum humidity for flight. This was between 50 and 54 percent in Minnesota and between 30 and 40 percent in Montana, a much drier area. The relationship was not well marked.

WIND. Stirrett (1938) stated that the flight of the European corn borer was not affected by winds with velocities up to 17 miles per hour. The writer had noted the same for flights of noctuid moths. This is definitely not true of their attraction to light. A wind of 10 miles per hour is sufficient to reduce the night's catch to nearly zero. Working with portable light traps, we have seen the catch of noctuids (and most other insects) cease abruptly with the coming up of a wind of 5 to 15 miles per hour. Because a portable anemometer was not used to measure these winds, definite wind data are lacking. However, after giving up trapping because of wind, we have repeatedly seen numbers of moths still flying around, and found them feeding at flowers.

The general conclusion regarding wind is that it does not influence moth flight greatly if other conditions are favorable, but that it practically inhibits their coming to lights.

ATMOSPHERIC PRESSURE. This apparently has little effect on either flight or photosensitivity. References in the literature largely refer to conditions before a storm. Here temperature, humidity, and wind, as well as pressure, are liable to be well within the optimum range.

RAINSTORMS. No definite data. Light traps run in sheltered locations in rainy weather appear to capture as many moths as on rainless nights, if other conditions are favorable. Moths often flock to lighted windows on rainy nights.

ELECTRIC STATE OF THE ATMOSPHERE. Moths are apparently stimulated to flight in thunderstorm weather, but it is difficult to disentangle any effects of atmospheric electricity from other influences. Heavy catches often precede storms.

CLOUDINESS. A cloudy night is usually a good night for moth trapping. Of course, the presence of clouds cuts out moonlight, if it would be present, and holds in the warm air against radiation, thus making conditions favorable. In the absence of useful data, the writer would say that a cloudy night is favorable for photosensitivity because temperature and humidity are liable to be high.

LUNAR PERIODICITY. Stirrett (1938) seemed to find very little correlation between lunar periodicity and flight of the corn borer. However, anyone who has used light traps found to his sorrow that the presence of a full moon will greatly reduce his captures. This is so marked that it has become quite usual to cease trapping operations for a few days around full moon. Dirks (1937) in his studies of the trapping of moths in Maine presented a table showing strongly the effect of moonlight on his catches.

In an attempt to obtain some quantitative data, some of the same index catches used for correlation with temperature changes above were tabulated with respect to their relation to full moon and new moon, respectively. The date of the moon's change was taken as zero, and the catches 1 and 2 days before and 1 and 2 days after the change tabulated. Since this took only 10 days out of the month, and the trap was not run on many nights around full moon, about 15 to 20 instances were obtained for each day. When the catches were averaged, it was found that those around the new moon ran between 92 and 117 percent of the normal catch, but those for full moon and the preceding night were 77 and 71 percent, respectively. The full moon rises at sunset, and comes up about an hour later each evening. Thus, the 77 percent catch the night of full moon rises to 102 the following night, and stays around 100 for the next two nights. The catches before full moon reflect the presence of the moon during early evening.

GOOD NIGHTS AND POOR NIGHTS. All operators of light traps have noticed this variation, which is often not subject to explanation. Williams stated that good nights were those in which the moths started flying soon after sunset and continued to fly throughout the greater part of the night. On poor nights the flight started at a lower level and fell off rather rapidly.

FOG OR MIST. Stirrett gives the only information I could find on these points. Fogs were very infrequent during his period of study, but he concluded that they had little influence on the flight of moths. This does not mean, however, that light trap catches might not be affected, as fog would reduce the distance from which the trap would be visible, and cut down its effectiveness to that extent.

DEW AND GUTTATION. Stirrett found no relation of these factors to moth flight.

RELATIONSHIP OF PHYSIOLOGICAL DEVELOPMENT AND CONDITION OF INSECTS TO PHOTOSENSITIVITY

H. Tashiro [1]

Literature is replete with studies on the photosensitivity of insects, but rather limited and fragmentary as it relates directly to the physiological development or condition of insects. Much of it is only indirectly related to this specific topic.

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This subject will be discussed, therefore, under two general categories--(1) that which directly relates to the physiology of the organ of sight or the physiological development of the insect and (2) that which is more or less indirectly related.

Phototropic response of the codling moth and the physiology of the compound eye. One of the most significant studies to relate the physiology of the compound eye to photosensitivity was conducted on the codling moth (3, 4, 5).[2] In ordinary behavior the moths are at rest during the day. As evening approaches they fly around the upper and outer leaves, engage in mating flights, and in oviposition. At darkness their activities cease more or less abruptly. Activity starts at about 30 foot-candles, increases to about 1 foot-candle, and stops at zero. They remain inactive throughout the night even in the brightest of moonlight. Activity is resumed again at dusk at the same light intensities.

The two periods of inactivity were found to be due to the adaptation of the compound eyes. During the day they are said to be in the light-adapted condition; during the night, in the dark-adapted condition. Moths that were exposed to varying degrees of illumination from daylight to darkness were killed and fixed at known intervals and histological studies were made of pigment distribution in the compound eyes. The iris pigment migration was found chiefly responsible for moths being in these two states. In the light-adapted condition the iris pigment is withdrawn from the area of the crystalline cones and migrates towards the apices of the retinulae cells. The retinulae pigment is distributed throughout their cells. Pigment distribution thus prevents sufficient light from reaching the retina to cause a phototropic response. In the dark-adapted condition there is a dense mantle of iris pigment around each crystalline cone and withdrawal of the retinulae pigment towards the basement membrane.

Under natural light, migrations of pigment from the light to the dark-adapted condition or vice versa required about an hour. Natural field populations of moths were killed and fixed at intervals from 5 p.m. to 5 a.m. Dark adaptation did not begin until about 15 minutes before sunset and was completed 30 to 50 minutes after sunset. Migration towards light adaptation started about 30 minutes before sunrise and was completed about 30 minutes after sunrise. Light traps with mercury vapor and tungsten lamps were exposed to moths in the orchard. In the presence of artificial light, the moths ceased normal activity as usual, but after 5 to 30 minutes resumed activity in response to the stimulus of artificial light.

Moths became phototropic in the transitional stage at three-quarters to seven-eighths dark-adapted condition and continued during the first hour of complete dark adaptation. Pigment migration proceeded more rapidly under the influence of ultraviolet light than under "white" light.

The following conclusions were reached: The vital activities of the moths are carried on almost exclusively during periods of changing light intensity. Iris-pigment migration adapts the eye to fluctuations in the light environment. The moth's reaction to either constant or changing light varies according to the position of the iris pigment. Iris pigment migrations are thus a prominent factor in determining behavior of moths. Of two light sources of the same continuous spectrum, the most billiant source elicits more rapid pigment migration and is the more attractive. Of two light sources of unequal spectral range, the one that evokes the more rapid pigment migration even though intensity and relative energy is less is the more attractive.

Adaptation to light sensitivity. Roeder (19) states that under constant stimulation the eye becomes adapted so the animal may no longer respond to illumination. An increase in intensity is required to cause recurrence of a response. Light adaptation may be described as a loss in sensitivity. It is a reversible process and sensitivity can be induced by subjecting the eye to darkness long enough to bring about dark adaptation. This adaptation was studied in the honey bee (24) by using a postural reaction of the antennae in response to moving stripes of light as the indicator. The logarithm of threshold intensity in millilamberts from 0 to -3 was plotted against time in minutes that bees were held in darkness. The curve showed that the sensitivity of the light-adapted

[2] Figures in parentheses refer to literature cited at end of this paper.

eyes increased rapidly during the first few minutes in darkness then more slowly until it reached a maximum sensitivity in bees held for 25 to 30 minutes in darkness. With no further increase in sensitivity the process of dark-adaptation was said to be complete.

Predisposition and response to light. Numerous studies have been made on the photosensitivity of insects that had been predisposed to certain conditions. Honey bees were trained (17) to come to food in a trough illuminated at 3650 angstroms (A.). Food was removed and the entire spectrum was projected on white paper. Bees congregated for the most part on the area subjected to 3650 A. even in the absence of food.

Von Frisch (12) in studies to determine whether chroma vision existed in the honey bees conditioned them to given colors. He then placed squares of this color on a checkerboard of grays. The bees could pick given colors regardless of their position on the checkerboard, but could not distinguish red. Those conditioned to yellow confused yellow, orange, and yellow green; those that were conditioned to blue confused blue, violet and purple.

A similar sort of preconditioning was performed in studying color discrimination in droneflies (16).

Mosquito larvae of the genus Culex and Aedes indicated the influence of diet on phototropism (20). Larvae fed on a mixed diet of pond organisms were positively phototropic. When fed a pure ciliate diet, they changed from a positive to negatively phototropic response in two days.

Age of insects and spectral sensitivity. Insects as a class respond to electromagnetic radiation in the approximate range of 2537 to 7000 A., from the ultraviolet to the infrared. It is generally agreed that most insects show greatest sensitivity to the near ultraviolet region, a gradual decline to the blue, an increase to a secondary peak in the blue-blue green region, and the least attraction to the longer wavelengths. The intensity of light plays an important role. It was shown (23) that at an introductory intensity of 100, peak response for most of 29 species took place at 4700-5280 A., but at an introductory intensity of 3 the peak response was at 3650-3663 A. This phenomenon confirms the belief that a "Purkenji shift" occurs in insects (10). This is a shift of overall sensitivity to shorter wavelengths under low illumination.

The spectral sensitivity of the larvae of 16 species of insects was determined (23). Nine were most sensitive to 3650 A.; the balance to 4920-5150 A. Unfortunately, in only 1 species, the Colorado potato beetle, was the sensitivity determined for both larva and adult. Both stages showed maximum sensitivity to 3650 A. with a secondary peak at 4920 A. Only 1 reference (23) was found that indicated the influence of age to photosensitivity. Drosophila adults 3 to 4 days old were less interested in light than individuals 6 to 8 days old. Those in the most responsive stages were highly sensitive to small amounts of ultraviolet radiation.

The foregoing remarks are chiefly of academic interest, but serve to illustrate the diversity in insect phototropism. There is no doubt but that a greater fund of basic information would lead to a more logical pursuit of practical problems. The remarks that follow relate only indirectly to the physiological development of insects to photosensitivity. They are reports on observations made almost exclusively in the field.

Meteorological influence on insect activity, not on photosensitivity. It is reported that most Lepidoptera are definitely inhibited at temperatures below 60° F. and are the most active at 65° to 70° F. (6). Codling moths in New Mexico (8) were inhibited in flight at temperatures above 80° or below 60° F. When temperatures dropped below 58° to 60° F., flight and catches of corn borer moths in light traps decreased rapidly even on nights when maximum flights were expected (9). The influence of wind on flight activities has been recorded. Corn borer moths (22) flew above corn tops when the night was still but flew below the tops when night was breezy and blacklight traps caught moths accordingly. The effect of temperature and wind action on pink bollworm moths was observed (13).

Below 60° few moths were taken. With favorable temperatures few moths were captured when the wind velocity was 10 m.p.h. or more, but at 6 m.p.h. many were captured. It appears quite evident that low catches during periods of unfavorable meterological conditions are the result of inhibited insect activity rather than an influence on photo-sensitivity.

Period of night and response to induced light. Considerable variation is apparent in this regard. In Mississippi (15) it was concluded that the time between 1 a.m. and 3 a.m. was the turning point for activity of all major insect groups in their response to light traps. Response of corn borer to light traps in Indiana (9) began at dusk, maximum flight reached between 11 p.m. and 2 a.m., and dropped off rapidly after 2 a.m. Pink bollworm moths (13) responded to blacklight in greatest numbers between 2 and 4 a.m. Observations on the European chafer in 1958 and 59 revealed another pattern of response to blacklight. Greatest response occurred before midnight, with a lull in activity during the middle of the night, and a secondary peak of activity after 3 a.m.

Sexual response to induced light. It has long been surmised that males were stimulated more than females to light stimulus. This belief, it is stated, was found in general to be erroneous and that both sexes are apparently equally responsive. When only 1 sex is taken it generally indicates sexual difference in time and place. Females usually fly only after mating, but males fly constantly in search for females. Males are said to fly higher than females (11). Results often do not bear out these generalities. In trapping mixed populations of 28 species of noctuid moths throughout the night male catches increased through the night while that of the females remained quite constant. Males increased from 52 percent during 7 to 9 p.m. to 81 percent during 3 to 5 a.m. Most females were caught in a trap 16 feet high and most males at 4 feet (7). The sexual response of pink bollworm moths to light traps was observed during 3 successive years in Texas. The field population is considered to have a sex ratio of 1:1. In 1952, 70 to 75 percent of the moths captured were males (13), in 1953, 74 percent of total catches were males (18), and in 1954 the vertical position of blacklight did not influence the preponderance of males (14). From 55 to 72 percent of all codling moths captured in light traps in New York, Pennsylvania, Indiana, and California (5) were males. A 3-year study of hornworm moths in tobacco fields caught in blacklight traps was made. Of the total tobacco hornworms, 82 percent were males, but only 54 percent of the tomato hornworms were males (21). Sexual response of stable flies was influenced by intensity. At wavelengths of 3650 to 4900 A. and low intensities, males responded more readily than females, but at higher intensities the males were less responsive than females (1).

A few figures are available for Coleoptera. The members of the genus Phyllophaga are reported (2) to show no significant sex preference for any of the colored lights to which they are exposed. Field populations of the European chafer have a male to female ratio of approximately 2:1. In 1958, 62 percent of all the beetles captured in blacklight traps were females. During 1959 the trend was the same with 53 percent of all beetles captured in blacklight traps being females. Neither period of season, location, or period of night influenced the sexual response of the beetles to blacklight.

Position of lights and insect response. The vertical position of blacklight traps and response of pink bollworm moths were studied by placing traps at 2-foot intervals from 2 to 14 feet (14). There was a progressive decrease in moths captured from the lowest position with 39 percent to the highest position with only 6 percent of the total captured. In a mixed population of moths (7) blacklight traps placed at 16-foot elevation caught equally as many moths as did the one placed at the 4-foot level. Traps at the 8- and 12-foot level caught equally low numbers. The position of the blacklight trap in relation to the position of the European chafer was of considerable importance. In the evening the beetles emerged from the ground and flew into nearby trees without paying any attention to the light traps. After coming to rest in the trees they were attracted to the lights. In 1959 it was determined that the position of the trap in relation to the tree on which beetles congregated was of prime importance. More beetles were captured in traps directly under the tree or at its periphery than traps out in the open.

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SECTION III--ROLE OF LIGHT TRAPS IN MEETING INSECT PROBLEMS

LIGHT TRAPS FOR DETECTION

Perry A. Glick[1]

INTRODUCTION

Observations and studies of insect response to light were made as early as 1856 by Belchard. It is probable, however, that no definite collections of insects using trapping devices were made until about 1886. Traps were used before 1904 by Vosseler, as reported by Busck (1917). Before 1906, Maxwell-Lefroy used light traps for detection of the pink bollworm moth.

My first experience with a light trap was in 1914. During the summer of that year a prominent collector of Lepidoptera, A. F. Porter of Decorah, Iowa, visited me at my old home in Missouri. Using a light trap, he had made several collecting expeditions in the head-hunting regions of the Amazon. His trap was unidirectional, using a small carbide lamp equipped with an autolight reflector, and the regular cyanide jar for collecting the specimens. The trap was quite effective, although mostly species of moths belonging to the families Arctiidae and Phalaenidae were collected.

Continuing from the early part of the 20th century, references to light traps increased considerably. When electric lamps, emitting radiant energy in the near ultraviolet and visible regions of the electromagnetic spectrum, were found more effective in attracting most nocturnal insects, light-trap design became greatly modified. The number of insects and species taken greatly increased, until it was possible and practical to make seasonal surveys and records of insects, particularly those of economic importance.

It appears that a single 15-watt black-light fluorescent lamp is preferable for general use. The argon lamp is more selective, attracting a smaller number of Orthoptera, Coleoptera, and aquatic Hemiptera, thus allowing the microlepidoptera to be easily examined. This type of lamp is being generally used for pink bollworm detection.

If a given species is known to be phototropic to the type of lamp used in a light trap and is not taken in the trap operated throughout the year in a specific locality, it may be assumed that the species is not abundant or does not occur. If the species is known to occur and to be rare, the chances of taking the insect may be small, especially if the trap is not properly located.

THE USE OF LIGHT TRAPS

Light traps serve as an important and valuable method in collecting crepuscular and nocturnal insects for taxonomic purposes, for detection of the presence of insect pests, to determine population changes or trends, and to aid in predicting potential infestations.

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COLLECTIONS FOR TAXONOMIC PURPOSES

Diurnal species of insects are seldom taken in light traps, since they do not respond to forms of artificial light. However, a few species of butterflies belonging to the families Pieridae, Lycaenidae, and Nymphalidae are occasionally taken, particularly during migration periods when the population level is particularly high. Whether the lights directly attract them, or they fall into the trap by chance has not been determined. Certain species of nocturnal insects may occur abundantly, but seldom are attracted to lights. There may be a sexual difference in response to light within a species, as often the males are taken in abundance, but the females rarely or vice versa. However, Robinson (1952) considers that as far as he was able to discover, the sexes, if they are night-flying, are equally susceptible to diversion to bright lights and any differentiation, in representative catches, is due to the fact that the two sexes fly in different areas.

As previously mentioned, certain species of moths may seldom if ever be seen or collected without the use of light traps. While using a black-light trap in Rock Creek Canyon near Colorado Springs, Colo., in August 1953, the writer took 15 specimens of the supposedly rare arctiid moth, "The Painted Arachnis", (Arachnis picta Packard) in one night. A veteran collector of Lepidoptera, the late J. F. May, remarked in great amazement at the time that he had neither collected nor seen a specimen of this species in 40 years.

Many phalaenid moths, particularly Catocala spp., some of which are extremely rare or difficult to collect, often may be taken in numbers in the traps. This may be said of genera and species of other orders as well. On a trip to southeastern Mexico in company of Dr. F. C. Bishopp, a portable black-light trap was used on several occasions, and a number of moths were taken which would otherwise not have been collected.

Russian entomologists apparently have begun to realize the importance of the use of light traps as indicated in an article by G. A. Mazokhin-Porshniakov (1956), in which he states: "Light traps with a mercury vapor lamp can be utilized not only for the sake of faunistic collections of insects, but also for the study of dynamics of flight of injurious species which is extremely important to applied entomology." He further commented that the use of mercury vapor lamps lead to evidence of new possibilities for the study of entomo-faunas by the utilization of this source of light. It was interesting to find that this article refers to work done on light traps by Hollingsworth and Glick in 1954.

Some English entomologists have predicted that the excessive use of light traps may cause a rapid disappearance of many rare and fine species in Great Britain, including Catocala fraxini, which collectors trapped by tens and hundreds of specimens every evening.

DETECTION FOR INSECT PESTS

An important use of light traps is to determine the presence of insect pests in an area, and to record throughout the year their population changes.

Since possibly the greater percentage of the injurious species of insects are crepuscular or nocturnal in habit, much valuable information can be obtained from records of various important economic insects taken in the traps, particularly before they are known to occur in an area, or before an infestation is noted.

A significant new use for the fluorescent black-light was reported by Haruro Tashiro (News Release 3266-58) in the attraction and capture of the grassland-destroying European chafer beetle. This was considered a definite breakthrough in the search for an effective means of determining the extent of the infestation and the need to establish

quarantine areas. It was found that there were up to 70 times more adult beetles captured in light than in chemically baited traps.

Adults of the pumpkin caterpillar (Diaphania indica) were first reported in light traps in Florida in 1959. However, upon reexamining collections of this genus, a specimen of this species was found to have been collected in Gainesville, Fla., in 1946. Apparently no attention was given to the occurrence of this caterpillar until light trap collections showed it to be found in a number of counties in Florida (USDA, CEIR, Jan. 8, 1960).

Numbers of specimens of Gonodonta pyrgo (Cramer), belonging to the group of fruit-piercing moths, were taken in a light trap in the summer of 1959 at the Texas Agricultural Experiment Station at Weslaco, Tex. This species is being closely watched as it has been previously reported as causing damage to orange and grapefruit in Panama by Zeteck in 1940, and later in Nicaragua in 1958 (Todd 1959). Gonodonta bidens Geyer was also reported for the first time in the United States, a specimen having been taken in a light trap at Weslaco on January 1, 1954. This species has also caused damage to citrus fruits in Mexico (Riherd and Wene 1955).

Traps have been used in cottonseed warehouses to detect any infestation in the seed. As early as 1920, Ballou used lamps for collecting pink bollworm moths in a large warehouse in Egypt, where cottonseed was stored, and collected several thousand moths in 8 days.

It is reported that several canning companies in Wisconsin used light traps in 1957 for detecting specific insects (USDA 809-58).

POPULATION CHANGES OR TRENDS

Considerable work was in progress in 1952 in collecting pink bollworm moths with light traps. These light trap studies were conducted in the Rio Grande Valley at San Benito, Tex., to determine the presence of the pink bollworm, and to correlate these findings with the degree of infestation occurring throughout the summer (Glick and Hollingsworth 1954). From April until June, few moths were collected. An excessively dry winter delayed the emergence of the moths. During May, nearly 6 inches of rain was recorded in the San Benito area, and in June about 2.5 inches. This amount of moisture, together with a rise in temperature, accelerated emergence of moths during this period. The emergence of these moths and the development of succeeding generations produced the large numbers taken in the light traps during July and August. In eight traps the monthly records per trap per night were 0.4 in March, 0.5 in May, 2.4 in June, 983.0 in July, and 484.8 in August. The high catches in July and August reflected the seasonal buildup in the pink bollworm population and maturity of the cotton. After stalk destruction date of August 31, the number of moths taken per night dropped to 31.9 in September, and 0.45 in October.

Light traps were also used in the Corpus Christi area, at Port Lavaca, Taft, Robstown, and Kenedy, from August to November 1952. Infestation was very heavy in this area, with the peak of trap collections in August, or a month later than the peak for the San Benito area.

In September 1952, black-light traps were placed in northeastern Texas along the Oklahoma-Texas Stateline, in the counties of Red River, Lamar, Fannin, Hopkins, and Bowie. In October, three moths were taken, one in each of the counties of Fannin, Lamar, and Red River (Glick and Hollingsworth, 1954). At that time these counties were not known to be infested with pink bollworm, and these findings indicated a spread from infested areas to the south and southwest.

On July 20, 1953, a light trap was installed at the Experiment Station at Tucumcari, N. Mex., and 30 pink bollworm moths were taken from September 4 to October 16. Infestation was found in one boll in October. In 1954 the trap was again in operation and 21 moths were taken from July 3 to September 10. No infestation was found in the fields in this area in 1954. The light trap was thus able to pick up moths in flight before infestation could be located in any of the fields.

In connection with a pink bollworm control and eradication program begun in Arizona in the summer of 1958, a series of light traps were used in Maricopa County, as well as other counties south, and in the Tucson area. Pink bollworm infestation was found in some fields, being particularly heavy near Gila Bend. To determine extent of the infestation, over 100 light traps, mostly of the argon type, were placed in locations with little known or unknown infestations. In several cases, moths were taken in the fields where inspection records were negative. This gave the Plant Pest Control Division, Agricultural Research Service, and State officials the much-needed information on the activity and occurrence of moths, which aided in determining the extent of the area where quarantine and control measures should be applied. Agricultural officials in California also cooperated in the extensive control program by placing over 100 argon traps in strategic locations along the California-Arizona Stateline and at other nearby locations where cotton was grown. This included areas from below Yuma, Ariz., up to Blyth, Calif., and Parker, Ariz. No moths were taken in the traps in these outlying areas.

The light trap program in Arizona and California was continued in the 1959 season, with additional traps installed in the cotton areas in both States. The numbers of moths taken in Arizona during the 1959 season were less than in 1958. The rigid control program undoubtedly reduced the potential infestation. Several pink bollworm moths were taken in a light trap in the Coronado National Forest area of Pima County, south of Tucson. The location of the trap was some 20 miles from the nearest cotton, but wild cotton (Thurberia thespesioides) grew around the trap. There was every evidence that the moths came from probable infestation in the wild cotton. No moths were ever taken in the light traps in California.

To obtain additional information on the activity of the pink bollworm moth in the air, a series of airplane flights was made in 1954 in the Rio Grande Valley of Texas, in which a number of pink bollworm moths were taken (Glick 1957). To supplement the data from altitudes below 200 feet, which heights were unsafe to make scheduled flights, light traps were placed at 100 feet on a water tower, on the roof of a hotel in Brownsville, Tex., and on the 85-foot catwalk level on an inactivated lighthouse at Port Isabel, Tex. During the summer, 159 moths were taken in the trap on the hotel, 7 on the water tower, but none on the lighthouse. It would appear that the factor of convection was important in aiding the moths to reach the trap on the hotel, since the surrounding pavement generated considerable radiation at night. The water tower, by contrast, was located in an open area where less radiation was present. Port Isabel, where the lighthouse stands, is on a promontory extending into the Gulf of Mexico. There is no cotton grown in this immediate area, and as the prevailing wind is from a southeasterly direction (from over the Gulf of Mexico), it would most likely account for no moths being taken in the trap.

Light trap collections of pink bollworm moths have been recorded for a number of years at the Brownsville Entomology Research Laboratory. Moths have been taken in some years as early as January 3 and 12, which was some weeks before cotton squares were locally available for propagation of the first spring generation. One female moth was taken on March 5, 1956, in a black-light trap on the El Jardin Hotel roof 100 feet in height.

PREDICTING POTENTIAL INFESTATION

In 1950 the Plant Pest Control Division, A.R.S., U.S.D.A., initiated a Cooperative Economic Insect Report, which is released weekly to all Federal entomological laboratories and agencies. Around 1954, light traps were used generally in this extensive survey.

At the present time some 24 States are in this cooperative arrangement, sending in weekly records of light-trap collections of the more important insect pests. Since records are collected throughout the year, particularly from traps located in the more Southern States, it is possible to follow species succession and occurrence. Often the presence of many species of insect pests may not be evident at a given time, yet with the use of light traps, emergence dates are closely determinable.

Continued improvement in light-trap design and construction, and lamp selectivity, which can be utilized for attracting insects in general or for specific species, will contribute greatly in the field of insect detection.

While some progress has been made in determining the distance of insect response to lamps, more detailed studies are necessary to meet the demands of both entomologists and farmers alike.

It is desirable to have a more efficient and practical portable light trap for use in detection work. The writer has received inquiries from many places in the world, such as the Belgian Congo, Australia, Iran, South America, and Mexico, as well as from our own country for such a type trap.

Light traps are an essential part of our entomological investigations, and the field for their continued use would appear unlimited.

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LIGHT TRAPS TO PREDICT NEED FOR CONTROL

[SUMMARY]

T. R. Pfrimmer[1]

Research work with light traps, as reported in the published literature, has been concerned primarily with:

1. The evaluation of light sources and/or trap designs for attracting and catching insects.
2. The determination of species, sex, seasonal occurrence, and other phases of the biology of insects collected by means of light traps.
3. The evaluation of light traps as a direct means of controlling or preventing injurious infestations of certain species of insects.

Very few published references were found which could be said to pertain directly to my subject. Some information has been gathered through correspondence and talks with various workers in this field.

Merkl and Pfrimmer (1955)[2] reported a high degree of correlation between the numbers of bollworm moths caught in light traps at Stoneville, Miss., and Tallulah, La., and the numbers of bollworm eggs per 100 terminals found in cottonfields in each area during the summer months of 1954. Although the data are not presented in their paper, Merkl and Pfrimmer also attempted to correlate the light-trap catches of bollworm moths with the number of bollworm larvae found per 100 terminals and the percent of bollworm-injured squares for each area. The correlations were not great enough to be significant. It is believed this was due at least in part to the intensive insecticidal control program being carried out in both areas against the boll weevil and other cotton insects.

Huffaker and Back (1943) stated: "For more than a decade the New Jersey mosquito trap has been used as a practical and very popular device for gaining information for use in the planning and operation of mosquito abatement programs in the Atlantic Coastal states. The development of this means of sampling mosquito populations must rank with the major recent accomplishments in the mosquito control field."

Marshall and Hienton (1938) said: "It has been suggested to apple producers that one or more light traps in the orchard around the packinghouse, or other farm buildings where apples have been stored, is an excellent means by which the daily flight activities of this insect (the codling moth) may be determined as an aid in the timing of sprays, thinning the fruit and timing other orchard operations which are determined by moth flight."

According to Howard Deay and J. H. Paullus, in Indiana and Illinois, light-trap data are used in timing the beginning and end of insecticidal applications for the European corn borer and the corn earworm. In Wisconsin recommendations for the control of corn earworms in canning sweet corn are timed by light-trap catches.

Light-trap collections have been used for the past 5 years to predict when insecticidal applications are needed for controlling the tomato fruitworm in Indiana. Timing of the first treatments for codling moth control in Wisconsin in 1959 was determined from light-trap catches.

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[2] For references in this paper, see section on Bibliography of Insects and Light at end of this publication.

Morris has used light-trap catches of carpenterworm moths on which to base the timing of trunk spray applications for the control of carpenterworms in hardwoods in Mississippi.

A study of the published data indicates the possibility of associating light-trap data with field infestations for predicting the need of control measures for the following insects: European corn borer, corn earworm, cotton bollworm, tomato fruitworm, mosquitoes, sand flies, codling moths, bud moth and leaf roller in apples, Asiatic garden beetle, white grubs, pink bollworm, armyworms, cutworms, cabbage loopers, and leafhoppers.

There are three more or less essential requirements that must be met before the use of light traps to predict the need for control can be successful.

1. There must be either an economically damaging infestation or a potentially damaging infestation of the insect or insects present in the locality.
2. The adults of the species involved must be nocturnal, positively phototropic insects.
3. There must be some knowledge of the biology of the species and a specific knowledge of the relationship between the light-trap catch and the field infestation.

At the present time the limitation on this use for light traps is number 3, particularly the lack of information on the correlation of light-trap catches and the field infestations.

Whether the light trap can be used as a direct survey tool or only as an indirect tool, supplementing other survey methods, will depend to a large extent on the insect and/or host involved.

The light-trap catch may indicate the presence of an insect in a given area in potentially damaging numbers, but the determination of the need for control measures in any given field in most instances still must be subject to a manual survey of that field for one or more of a number of reasons:

1. The crop in the field may not be attractive for oviposition.
2. Predators and parasites may prevent the infestation from ever developing.
3. Disease may wipe out the infestation before control measures are justified.
4. Climatic conditions may prevent the infestation from developing.
5. Host preference may cause the insect to go to another crop in the area.
6. Infestation may be spotted and not occur in all fields.
7. Chemical control measures in use in the field for another insect pest may keep down the infestation.

One advantage light traps have over more conventional survey methods is that one light trap properly located can furnish information on a number of economic species attacking a variety of crops, without having to go into the different fields to check for each insect. By using the light trap in this manner and by going into the specific crop to look for a specific insect pest only when the light trap catch has indicated the need to do so, a considerable saving in time and money can be effected over the present manual survey methods.

To summarize--some usage is already being made of light traps to predict the need for control. At present this use is rather limited. It is my belief that in the future the greatest field of usefulness for light traps will be as a survey tool--either as a direct method to predict the need for control, or as an indirect method, utilizing light-trap data to determine where specific manual surveys are needed.

The greatest need is for more investigations on the relationships between light-trap catches and field populations and the factors affecting this relationship. Research

is needed to determine the size of a light-trap catch necessary to indicate an economically damaging or potentially damaging infestation present in the area.

The ultimate extent to which light traps can be useful in predicting the need for control is limited only by the number of insect species of economic importance which are nocturnal and positively phototropic.

THE USE OF ELECTRIC LIGHT TRAPS AS AN INSECT CONTROL[1]

Howard O. Deay[2]

The use of electric light traps as an insect control is still in the experimental stage. Much basic research needs to be done by entomologists and agricultural engineers on this problem. However, the results of cooperative experiments conducted in Indiana by the Purdue Departments of Entomology and of Agricultural Engineering and the Farm Electrification Branch of the ARS indicate that satisfactory controls of certain insect species can be obtained with existing, commercially available light sources.

The use of light traps to protect plants from insects is based on the phototactic response of the adults. This response may be either positive or negative. Our work at Purdue on the control of agricultural pests has been concerned for the most part with the photopositive response. The controls may be either preventive or remedial. If preventive, the light traps must be installed and functioning before the adults deposit their eggs or injure the crops.

Not all species of insects are phototactic, therefore, it is self-evident that light traps will not be a panacea for all injurious insects in the field and that other types of insect control will be needed.

Some of the problems and/or disadvantages associated with the use of light traps as a control tool at present are: (1) The availability of electric power, (2) initial cost of the light traps, (3) the cost of field installations, (4) the destroying of the insects attracted to the traps, and (5) the accurate evaluation of the results obtained.

The major factors in the successful use of light traps for control are: (1) The "intensity" and power of the light source and the wavelengths of energy emitted, (2) the design of the trap and the location and spacing of the traps in the field, and (3) the physiology, ecology (especially the effects of the physical factors of the environment on the flight and phototactic response of insects), morphology, and life history of the insect species in question.

Some of the possible uses of light traps as an insect control are, as follows:

1. To protect growing plants from larvae and nymphs, by destroying the adults before they have mated or the females have deposited eggs, and from injurious adults.

2. To serve as a supplement to other types of insect control.

3. To control certain species of insects that have become resistant to insecticides.

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[1] Journal Paper No. 1716 of the Purdue University Agricultural Experiment Station, Lafayette, Ind.

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4. To assist in the prediction of insect outbreaks and the timing of insecticidal applications.
5. To assist in the detection of introduced insect pests.
6. To control insects in areas where other types of control cannot or should not be used.
7. To keep insects away from porches, yards, drive-in type of food establishments, and other outdoor areas.
8. To assist in the evaluation of results of other types of insect control.

Some of the advantages of the use of light traps are: (1) They leave no poisonous residues on crops. (2) They operate continuously, thereby eliminating the necessity of timing the application of the control measure used. (3) They operate when fields are wet as well as when dry. (4) The cost of operation is low--about 30 to 40 cents a month for one 15-watt lamp.

Results of Experiments to Protect Tobacco from Tobacco and Tomato Hornworms[3]

Experiments were conducted in six fields of tobacco in southern Indiana during the seasons of 1956-59. During 1959 the traps were operated by the farmers but the records were taken by the project personnel. Results of preliminary experiments in 1954 and 1955 indicated that a trap equipped with one 15-watt BL lamp would protect the tobacco within a radius of 100 to 120 feet from the lamp. The number of lamps used per field varied with the size and shape of the field. No insecticides were used in the treated fields and hand picking of worms was not practiced. Check fields were selected which were near the lighted ones (20 to 60 rods distance) and in which the tobacco had been planted at the same time as in the experimental fields. In all the check fields the growers practiced hand picking of the worms once or twice a week and insecticides were applied one or two times in certain of the years to some of the check fields. The use of insecticide, mostly because of poor application and timing, seemed to have little effect on the hornworm population and resulting damage.

The results for the 4 years' experiments are given in the following table:

Tobacco and Tomato Hornworm Damage to Tobacco
Jefferson County, Indiana

Year	Lighted fields		Unlighted fields	
	Plants infested	Leaves destroyed	Plants infested	Leaves destroyed
	Pct.	*Pct.*	*Pct.*	*Pct.*
1956	7.9	0.14	36.0	0.76
1957	11.8	.20	73.8	1.06
1958	7.0	.14	25.2	.55
1959*	16.6	.19	28.2	.60

*Farmer operated

Tobacco is harvested in southern Indiana from about August 20 to September 5. This early harvest accounts in part for the small amount of damage caused by the hornworms.

[3] Data for most part unpublished.

Results of Use of Electric Light Traps to Control Insects in the Home Vegetable Garden.[4]

Experiments were conducted in both 1958 and 1959. The season of 1958 was cool and wet; the total rainfall for May, June, July, and August was 29.41" or 13.95" above the normal of 15.46". In 1959 the rainfall was 6.11" below normal and the temperatures were normal or above. The experiment was set up in three blocks in 1958 and in four in 1959. Each block contained four 50' x 60' plots. Each plot contained six vegetables (beans, cabbage, cucumbers, potatoes, sweet corn (an early and a late planting), and tomatoes.) In each block one plot was protected by a trap containing a single 15-watt BL fluorescent lamp, a second by a trap containing one 15-watt BL and one 15-watt green fluorescent lamp, and a third by a trap containing three 15-watt BL lamps. The fourth plot in each block was unlighted and served as a check. The lighted and unlighted plots in each block were chosen at random. The plots were placed 230 feet apart in a 14-acre field in 1958 and a 16-acre one in 1959. No insecticides or fungicides were used on any of the plants in the experiment or in any of the adjacent fields.

Beans: The Mexican bean beetle was scarce in both 1958 and 1959 and rather evenly distributed in both the lighted and unlighted plots. The population of potato leafhoppers and the incidence of hopperburn were light but were heavier, but not significantly so, in the lighted than in the unlighted plots. Hopperburn was significantly heavier in the unlighted checks in 1959 than it was in the plots protected by the three BL lamps.

Cabbage: In 1958 imported cabbageworms and diamondback moth larvae were scarce and were evenly distributed throughout all plots. Damage was confined to outer leaves and no commercial damage occurred. The cabbage looper damage was light and rather uniform. In 1959 the imported cabbageworm population was very high and all plants were damaged severely.

Cucumbers: The yields for the 2 years are shown in the following table:

Average Yield in Weight and Numbers of Cucumbers Six Inches or More in Length

Treatments	1958 (Av. 3 Rep.)		1959 (Av. 4 Rep.)	
	Weight (lbs.)	Number	Weight (lbs.)	Number
Unlighted check	70.9	154	89.3	212
1 15-W BL lamp	118.8	293	116.2	280
1 15-W BL & 1 15-W green	183.8	388	98.2	232
3 15-W BL	328.4	665	147.0	331

In 1958 the yields were significantly better in all the treatments than in the checks. In 1959 the yields in the plots protected by the three 15-watt BL lamps were significantly higher than in the check plots. In 1958 the main reason for the differences in the yields seemed to be due to the number of plants that died from cucurbit wilt. In 1959, although there were 2x as many striped and 6x as many spotted cucumber beetles captured at the traps as in 1958, only half as many plants died from cucurbit wilt. Since the same number of plants survived until the last of August and the amount of feeding by the beetles was practically the same in both years in the plots protected by the three 15-watt BL lamps, it would seem that the lower yields obtained in 1959 can be attributed to the dry weather.

[4] See footnote 3.

Potatoes: There was some feeding in all plots by the Colorado potato beetle in both years. Hopperburn was more severe in all of the lighted than in the check plots in both years, with the difference being much greater in the dry year of 1959.

Sweet corn: In the early planted corn in 1958 there was little or no infestation of either the European corn borer or the corn earworm. In 1959 the early corn was infested by both of these insects, with the corn in the check plots having a significantly higher number of ears infested than did that in the lighted plots. In the late-planted sweet corn (harvested Sept. 19) in 1958, the number of ears infested by both the European corn borer and the corn earworm was significantly higher in the check than in the lighted plots. In 1959 (corn harvested Sept. 22), the number of ears infested by the corn borer was significantly higher in the check than in the lighted plots, but all ears in all plots were infested by the corn earworm. The population of corn earworms was higher in 1959 than in any year since 1938.

Tomatoes: The percent of plants infested in 1958 and 1959 which were infested by the tobacco and tomato hornworms is shown below:

Treatment	Percent Plants Infested	
	1958	1959
Check (Unlighted)	31	84
1 15-W BL lamp	4	34
1 15-W BL + 1 15-W green	3	19
3 15-W BL	0	26

In addition to the defoliation of the plants, the fruit in the check plots was severely damaged in 1959.

SUMMARY OF INFORMAL DISCUSSIONS

During the discussions following the presentation of prepared papers, many interesting ideas were expressed and pertinent suggestions made. The following is a brief summary of the more important of these ideas and suggestions.

It was emphasized that there were many difficulties in attempting to conduct precise scientific research using commercially available lamps. (1) No commercial lamp radiates at just one narrow band of frequencies, although the radiation in a relatively narrow band may predominate. Most lamps have some radiation in both the ultraviolet and the infrared although the radiation at the extreme frequencies may be quite small. (2) The nominal colors of commercial lamps are not an adequate characterization of such lamps for purposes of scientific research involving the differential insect responses because lamps from different manufacturers listed under the same color may vary considerably in the distribution of their radiation between frequencies. (3) Lamps from different manufacturers may respond differently to variations in line voltage.

The need for good control of voltage applied to lamps used in research was also emphasized and acknowledged as a rather difficult problem in many field studies. On the other hand, it was pointed out by representatives of industry that the research laboratories of commercial companies frequently had unpublicized experimental, semi-experimental or even low volume, little advertised commercial devices which might be very useful tools for public agency research projects. There is need for better communication between the two groups.

For example, infrared (heat region) lamps with nichrome wire filament in quartz glass bulbs and luminescent plates are available. The former radiates heat with little or no visible light and the latter radiates energy nearly all of which is between the ultraviolet and infrared with uniform brightness over the entire surface of almost any area desired. The luminescent plates are available in many colors. Neither of these devices had been used in any of the research reported by the prepared papers.

It was brought out in the discussion that more research was needed on the relative importance of spectral distribution versus total energy output of light sources as well as the relative effectiveness of a point source as opposed to a larger area with the same total energy output.

The need for further study of the response of insects to various types of flashing or flickering was emphasized. Although limited research on this phase was reported, it was pointed out that such light sources have many variables, most of which have been inadequately studied.

It was also suggested that more intensive research was needed on the response of insects to infrared (heat) radiation and that the complete spectrum of sound waves also should be thoroughly investigated.

The need for intensive basic studies of the physics, chemistry, and biology of insect response to stimuli was especially emphasized. It was pointed out that most of the research tools needed for such investigations are available if the needed resources are allocated and the necessary effort made. For example, in such studies illumination should be in actual physical quantities rather than footcandles or candlepower based on the response of the human eye. There is need to determine whether the insect's eye is the significant receptor, and whether the angle of the cells of the insect's compound eye is a significant factor in determining the wavelength of radiation to which it responds.

During this part of the discussion it was suggested that the secondary response of some insects to ultraviolet radiation at 3650 Angstrom units in addition to the major response to green at 5200 Angstrom units might be the result of fluorescence of the eyes of insects by the ultraviolet radiation.

It was also emphasized that basic study of insect response to induced light should not be limited to motor response or movement, and that diapause, photoperiodism, growth, mating, and other physiological changes should be investigated.

There was considerable discussion on the effects of location and environment of a light trap on its performance. It was pointed out that two apparently similar locations sometimes gave very different results. The great importance of weather conditions was emphasized. One participant reported that in studying the effect of weather on insect activity men were recording 14 variables including air temperature, soil temperature, wind direction and velocity, barometric pressure, relative humidity, rain, sunshine, and atmospheric electricity. There appears to be evidence that atmospheric electricity and ionization are not being adequately considered.

It was pointed out that though many canning companies are using the light trap as a tool for survey to guide in the application of other control methods, much research is needed to determine the spacing and number of traps needed, to evaluate the significance of catches of different insects under different conditions and to develop and improve traps needed for different uses.

It was further pointed out that insect surveys, to be most effective, should start early in the season in order to record the initiation of insect activities and follow population trends. In addition, the small catches of insects obtained when populations are low permit satisfactory identification and analysis. Later when insect populations are high, the number of insects caught (frequently of nonsignificant species) may make sorting for identification very difficult.

The importance of any insect control method which does not require a toxic chemical was emphasized as justifying continued investigation of light and sound as control or supplementary control tools.

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